A SYSTEM

OF

ELECTROTHERAPEUTICS

INTERNATIONAL CORRESPONDENCE SCHOOLS

SCRANTON, PA.

DIRECT CURRENTS

MAGNETISM AND ELECTROMAGNETISM

ELECTROSTATICS AND HIGH-FREQUENCY CURRENTS

ACCESSORY APPARATUS

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SCHOOL OF ELECTROTHERAPEUTICS

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PREFACE.

Since the publication of the first edition many advances have been made in electrotherapeutics, particularly in the field of the application of Roentgen rays for diagnostic and curative purposes. The field of the faradic current has been widened by the more extensive use of the sinusoidal current, whereby valuable aid has been given in cases where the faradic current alone was unable to produce the desired effects. The combination of the direct current either with the faradic or the sinusoidal current is also a method that has received a more extensive application. Diagnosis as applicable to orthopedic surgery by means of the electric current is still another branch of electrotherapeutics that has been growing in importance.

All these, besides numerous other subjects, have been incorporated in the present volumes. The original text has, to a large extent, been rewritten, not only to bring it fully up to date, but also to elucidate some subjects that seemed to need a fuller treatment. Every effort has been expended to incorporate information regarding the latest advances in France, Germany, England, and the United States.

The Electrotherapeutic Course was planned by, and prepared under the supervision of, W. F. Brady, M. D. His aim has been to have the various Papers contained in the Course supplied by specialists that have had an extensive experience in their respective branches. The following is a list of the principal Papers and their authors:

Electricity in Diseases of the Nervous System, and Electricity in Surgery, by W. J. Herdman, M. D., LL.D., Professor of Diseases of the Mind and Nervous System, of the University of Michigan.

Practical Application of Roentgen Rays, by Carl Beck, M. D., Visiting Surgeon St. Mark's Hospital and the German Polyclinic of the City of New York.

Electricity in Genito-Urinary Diseases, by Robert Newman, M. D., Consulting Surgeon, Hackensack Hospital, N. J.; Consulting Surgeon, Bayonne Hospital, N. J.; Consulting Surgeon, German Dispensary, New York, N. Y.; Consulting Surgeon, McDonough Memorial Hospital, New York, N. Y.; Consulting Physician, Home for Aged and Infirm, New York, N. Y.

Therapeutic Uses of Electricity in Gynecology, by Augustin H. Goelet, M. D., Professor of Gynecology and Abdominal Surgery, New York School of Clinical Medicine, New York, N. Y.

Therapeutic Uses of Static Currents, by S. H. Monell, author of "Treatment of Diseases by Electric Currents, and X-rays and Static Electricity," etc.

Electricity in Diseases of Eye, Ear, Nose, and Throat, by Carl C. Warden, Ph. B., M. D., Professor of Anatomy and Operative Surgery, University of Nashville, Tenn.

Electricity in Dentistry, by Levitt E. Custer, B. S., D. D. S., Lecturer upon Dental Electricity in Ohio College of Dental Surgery; Member of National Dental Association, etc.

Technique and Physiology of Static and Other High-Frequency Currents, Technique and Physiology of Direct Currents, and Technique and Physiology of Coil-Currents, by W. F. Brady, M. D.

All the Papers in the volume entitled Electrophysics, and, in addition, Physics of Roentgen Rays, Skiagraphy, Physics of Light and Cautery, and certain portions of other Papers were written by D. C. Reusch, M. E. The latter had the opportunity of studying electricity in the Dresden laboratory of Professor Toepler, the well-known inventor of the static induction-machine, now so extensively used in electro-therapeutics.

The first two volumes may be said to constitute the foundation of this Course, and great pains have therefore been taken to make these as complete and clear as possible, for which reasons numerous novel methods and analogies have been made use of, not to be found in print elsewhere.

The whole Course comprises eighteen Instruction Papers, which are issued in bound volumes and in pamphlets. In this latter form they are supplied to students as they proceed through the Course. The bound volumes will make a desirable acquisition to any medical library, especially as a work of reference.

The method of numbering the pages, cuts, articles, etc. is such that each Paper and part is complete in itself; hence, in order to make the indexes intelligible, it was necessary to give each Paper and part a number. This number is placed at the top of each page, on the headline, opposite the page number, and to distinguish it from the page number it is preceded by a printer's section mark §. Consequently, a reference such as § 3, page 29, would be readily found by looking along the headlines until § 3 is found, and then through § 3 until page 29 is found.

The Examination Questions are given the same section and numbers as the Instruction Papers to which they belong, and are grouped together at the end of the volume containing the Instruction Papers to which they refer.

INTERNATIONAL CORRESPONDENCE SCHOOLS.

CONTENTS.

DIRECT CURRENTS.

NATURE OF ELECTRICITY.

1. Electricity an Exact Science.—It has often been remarked that "electricity is a mystery"; so it is, and so too are gravitation, heat, and light, for in none of these cases is it known exactly in what manner the energy acts on matter. But this does not make the science of these forces any less exact, nor does it necessarily mean that we are fumbling in the dark, nor that the laws of these phenomena may be upset at any moment by new discoveries.

No one will say that astronomy is not an exact science; and yet the origin of that force upon the action of which all astronomical laws are based is yet to be explained. Notwithstanding all this, it has been possible to determine years ahead the transit of the planets, and within the fraction of a second. Nevertheless, our knowledge of the force of gravitation is far more limited than our knowledge of electricity. In the latter instance, it is possible to at least establish a current, to conduct it, and to regulate it at will. It is also possible to study the action of the current in all its possible combinations, and new discoveries are continually bringing us nearer to the solution of the question, "What is electricity?" Not so with gravitation; while great progress has been made in other sciences, our knowledge about the inner nature of gravitation is no further advanced than it was ages ago, and no immediate progress is in view.

As with gravitation, so it is with electricity; ignorance of its nature has not prevented the study of its action, and very exact laws have been established. By means of these laws we are enabled to predict beforehand, and without fail, what will take place under certain prearranged conditions.

2. Currents of Electricity.—The popular impression is that electricity is something that flows along a wire; that it can be tapped and be carried away, if need be; that it is more or less a substance. Formerly, the phenomena of heat, of light, of magnetism, and of electricity were all supposed to be actions of fluids; even today we speak of *currents of electricity* and *of magnetism*. Though it is very convenient when speaking of various electrical phenomena to consider electricity as flowing from one place to another, it must not be taken too literally. It is more than likely that nothing happens that would compare at all with what we understand by the word *current*.

By *electricity* we do not understand a substance, but a condition. In the same manner, for instance, when speaking of an object as being hot or cold, we do not suppose that any material substance has been injected into the object to change its temperature. This was the belief in former days; at present, however, we know that the object, as a whole, is unchanged, but that its molecules are in a different condition. Our senses happen to be so organized that we are able to distinguish the changes in these molecular conditions without actual touch, but with electricity this is different. An electric conductor carrying a high-tension current cannot be distinguished from any other conductor until touched. If this were possible, many lives might have been saved. This comparison between electricity and heat should not be taken to mean that electricity itself is a molecular phenomenon. The primal cause of an electric current may be molecular rearrangements; the vehicle through which electricity primarily acts, however, is not supposed to be the material molecules, but something else. What this vehicle really is we can only guess at, as its qualities are hypothetic. Without it we would be at a loss to explain both the phenomena of magnetism and electricity, as well as light, radiant heat, and gravitation.

3. The Ether.—Science supposes that all space, even between the molecules of a body, is filled with a medium called **ether,** which is supposed to be 1,000,000 times less dense than water and, therefore, would present no obstruction to the motion of planetary bodies. To explain how the ether is able to transmit the waves of light, it is supposed to be less compressible than water, when subjected to quick vibrations. We must consider it the one universal medium, and that by its means all actions between separate bodies are carried on. In brief, its function is to act as a transmitter of motion and energy.

If a bell is vibrating in a glass vessel, the sound can be heard from the outside; but if the vessel is put in communication with an air-pump and exhausted, the sound grows fainter and fainter as the vacuum increases, showing that the sound needs the air for its transmission. We find that a magnet enclosed in a glass vessel is just as active when the vessel is exhausted as when it is not. The filament of an incandescent lamp, although it glows in a vacuum, is visible from the outside of the globe, proving that air is not necessary for the transmission of light. Perhaps it may not be necessary to go further into the manifestations of the ether, yet more proofs of its existence may be given. For instance, the sun's rays of heat and light are transmitted through space, where it would be impossible for them to travel without the presence of some such medium as ether. It has also been noticed that an increase in the number of visible spots on the surface of the sun has a marked influence on magnetic needles, proving that the force of magnetism or electricity also travels through an apparently empty space.

In summing up these remarks about electricity and ether, it must be admitted that science in its present state is unable to inform us about the real nature of electricity. It is able to say what electricity is not and what it may be, and it is perhaps near the truth to say that electricity is a peculiar state of matter, a certain condition of the ether.

ELECTRICAL UNITS.

THE COULOMB.

4. **Electromotive Force.**—In applying electricity to our daily needs, it is always a question of producing an *electric pressure*, not of producing electricity, which may be supposed to be already in existence. In the same manner, when it is desired to utilize water for power purposes, for driving mills, etc., we do not produce the water, as this is provided by nature. The water is led to our motors after having been put in such a condition that it will be under pressure and able to drive the motors. This might be done by first pumping the water into an elevated reservoir, thus placing it in a position that will enable it to return the work spent in pumping it up, usually by conducting it through a pipe to a waterwheel or turbine. But this would be useless expense and work, as in most cases nature has already performed the work for us by depositing the water in elevated places in the form of lakes, etc., and all that is necessary is to provide a path for the water to reach our motors.

With electricity this is not the case. Nature, in this instance, has provided no storehouse for us, and we are obliged to raise electricity to a higher pressure, or potential, before we are able to utilize it for our purposes. This may be done in various ways. On a large scale, as for instance, for lighting cities or supplying their trolley-lines with power, it is usually done by transforming the energy that is stored up in coal into heat under steam-boilers and transforming this heat energy into mechanical energy by means of a steam-engine. By letting the latter drive machines in which electric pressure is produced, such as dynamos, we are able to furnish a current of electricity for the various purposes required. On a smaller scale, electric pressure may be produced by means of the voltaic cell, which will be fully described further on. Also, in this case, a combustion takes place, but here it is zinc and not coal that is the material consumed. When zinc, under ordinary circumstances, is burned in oxygen, it will give out heat; when consumed in a voltaic cell, however, by combining with the oxygen of the fluid contained in the cell, it will not ordinarily change its energy into heat, but into electric energy. It will be a source of electric pressure.

This pressure, or force, that sets electricity in motion is called an **electromotive force,** and it is the cause of all electric phenomena. To set water in motion through a pipe, an excess of pressure must be caused somewhere in the pipe, that is, there must be a difference in pressure between the two places from and toward which the water shall flow. The same holds true with electricity. It is also here a question of producing a

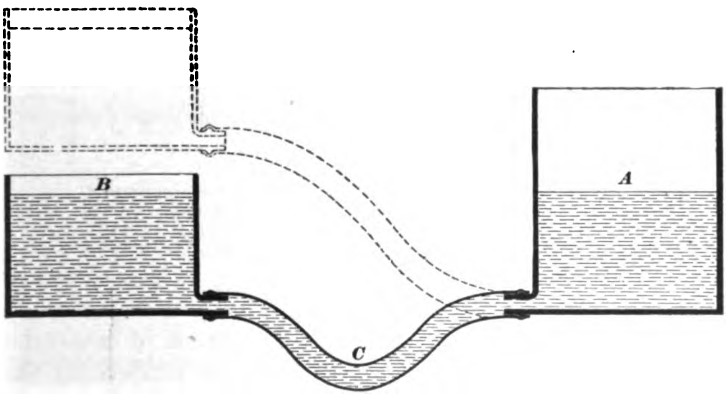


FIG. 1.

difference in pressure, or *potential*, that is, of raising the potential of a given quantity of electricity at one place to a higher value than the potential of another quantity at some other point, so that an equalization will tend to take place and a current of electricity will flow from the quantity of higher pressure, or potential, to that of lower potential, seeking to eliminate the difference of potential between the two quantities.

Fig. 1 will illustrate this more fully. *A* and *B* are two tanks partly filled with water and connected by the tube *C*. If the water is on the same level in each tank, as indicated by the full lines, it will be at rest and have no tendency to flow in either direction; but if the tank *B* is raised to the position indicated by the dotted lines, the conditions are changed, and the water has a tendency to again place itself at the same level. There will, therefore, be a flow from *B* toward *A* until balance is restored. If the water is prevented from flowing by placing a valve in the tube, there will still be a pressure at one end of the tube, and this will vanish only when the tank *B* is returned to its original position. Electricity under pressure behaves very much in the same manner. If a difference of potential has been produced between two quantities, or charges, of electricity, equalization will at once tend to take place; and if a flow is prevented by some means, a current will be established as soon as the obstruction has been removed. The cause of this flow — the electromotive force — has also been given other names such as *difference of potential*, *pressure*, *tension*, and *voltage*. Electromotive force is usually abbreviated to E. M. F. A more complete explanation of these terms will be given later.

5. Quantity.— After it has been shown that an E. M. F. will cause electricity to flow from one place to another, it is important to ascertain *how much* electricity is under certain conditions transferred.

There is some similarity between the methods of measuring water and electricity, and it will simplify matters to first consider the method of measuring water. Suppose we have to pay a water company for the amount of water actually used. The question is then how to conveniently measure the amount delivered through the faucets. A primitive method would be to have a gallon-measure and count the number of gallons taken from the faucet. This would, of course, be a very inconvenient and impracticable method to carry out. Another way would be to measure the *speed* with which the water flows through the pipe, and from this calculate the quantity, or number of gallons, that passes through. A water-meter could be so constructed that it would indicate at any moment the number of gallons that flow per minute. If, for instance, the water were flowing for 5 minutes at a rate of 10 gallons per minute, we would know that 50 gallons had been received. Should the water-pressure have been reduced so that the water would flow more slowly through the pipe, the meter would at once indicate such change. We see, then, that the meter indicates the *rate* at which the water flows through the pipe, that is, it indicates the number of gallons passing through per second or per minute, as the case may be.

In Fig. 2, water is flowing through a tube *A*, and it is desired to ascertain by means of some device the rate at which the water is passing a given point, that is, the number of gallons or other units agreed on that will pass per minute or per second. If *b* is a small vane projecting into the tube, supported in a manner that will allow it to swing in the direction of the flow against the pressure of the spring *s*, it will be possible to use

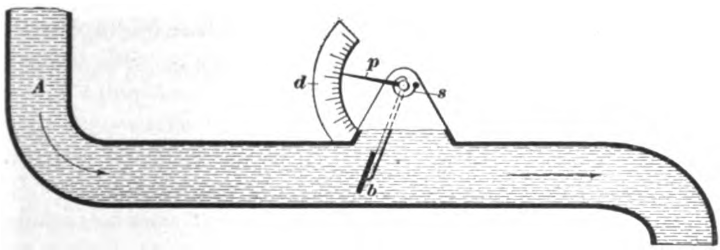


FIG. 2.

this device as an indicator of the rate at which the water flows. The faster the water passes through the tube, the more pressure will it exert on the vane and the farther will the pointer *p* move downward over the scale *d*. If this meter be compared with some other meter that measures the number of gallons that have actually passed through the tube *A* in a given time, it will be possible to let the divisions on the scale *d* indicate the various rates at which the water may flow in so many gallons per minute.

If, for instance, the pointer indicates 5, it will be a 5-gallon stream, meaning thereby 5 gallons per minute. Should this flow have been going on for 50 minutes, we would find the total amount discharged by multiplying 5 by 50, giving a product of 250 gallons. The indicator will not alone show us the average rate of flow, but will also indicate any sudden variations in the same. For instance, if the strength of the current should suddenly increase to 10 gallons per minute, such a change would at once be indicated by the pointer.

In an electric circuit, we have somewhat similar conditions. It may, in one case, be desirable to know the quantity of electricity that flows through a wire, irrespective of time; at other times, it may be necessary to know the *rate* of flow either at any particular moment or for a longer period.

6. Definition of Coulomb.—The electrical unit of quantity is the **coulomb.** It signifies a certain quantity of electricity, either at rest, distributed over the surface of some substance, or in motion along a wire. For the present, we shall consider the coulomb simply as the unit quantity of electricity flowing along a conductor. It should here be emphasized that when speaking of a coulomb no reference is made to time, that is, to the time it required to flow from one point in the circuit to another; we simply refer to a certain quantity. Similarly, when speaking of a gallon of water, we do not have any reference to the time it required to be poured out.

In order to give some idea of the amount of work a coulomb of electricity can accomplish when it, for instance, is sent through a liquid, further on we will describe the action of an electric current while passing through an instrument called a *voltameter.* This should not, by any means, be confounded with a *voltmeter*, which serves an entirely different purpose.

THE AMPERE.

7. Rate of Flow.—Ordinarily it is of less interest to us to know *how many* coulombs are transferred from one place to another than the *rate* at which these coulombs have been flowing through the conductors. As the unit rate of flow of electricity, the **ampere** has been chosen. When 1 coulomb passes a given point during 1 second of time, it is said that the rate of flow is 1 ampere. One ampere being 1 coulomb per second, an instrument that measures current-strength in amperes would indicate coulombs per second in the same manner as the device in Fig. 2 indicated gallons per minute..

8. Ammeters.—Instruments that measure amperes are called **ammeters,** and will be more fully described later.

In electrotherapeutics, currents of very small strengths are used and an ampere, as unit, would be too large. It has therefore been found more convenient to use $\frac{1}{1000}$ ampere as a unit, and this is called a **milliampere.**

It is now clear that if we divide the quantity in coulombs by the time in seconds, the quotient will give the strength in amperes; or, $\frac{\text{coulombs}}{\text{seconds}} = \text{amperes}$. Or, let c = amperes; Q = coulombs; and t = seconds; then, $c = \frac{Q}{t}$.

EXAMPLE.—If, in a conductor, 100 coulombs pass a certain point in 5 seconds, what is the current-strength in amperes?

SOLUTION.—Applying formula, $c = \frac{Q}{t}$, we get $\frac{100}{5} = 20$ amperes. Ans.

THE OHM.

9. Resistance.—An electric current does not pass with the same facility through all substances. It seems that various substances possess a certain obstructive quality and that the current meets with more or less opposition, which it has to overcome. In some substances this **resistance,** as the quality is termed, is very small; while in others it may be so great as to prevent a flow altogether. Substances of the latter class are called **insulators;** those that freely conduct the current are termed **conductors.** Other substances stand midway between these two classes and may be termed *semi-conductors* or *partial conductors.* Strictly speaking, there is no perfect conductor and no perfect insulator. All conductors offer some opposition to a current-flow, be it ever so small; and all insulators permit some current to pass when the pressure is sufficiently high and their surfaces not free from dust and moisture.

Among good *conductors* are included silver, copper, and the other metals, also carbon and water when acidulated. As *partial* *conductors* may be named the human body, cotton, dry wood, marble, and paper. Among the *non-conductors*, or *insulators*, are oils, porcelain, wool, silk, resin, gutta-percha, shellac, hard rubber, paraffin, glass, quartz, and air.

10. Relative Resistance.—For the purpose of affording a better comparison between the resistances of the various conductors, a piece of each substance has been taken and its resistance ascertained. A piece corresponding in dimensions to that of 1 cubic inch was selected for this purpose. In Fig. 3, *a* would correspond to the length and be 1 inch and *b* would be its cross-sectional area of 1 square inch. The electric current would flow from the surface *b* through a length of 1 inch to the other surface *c*.

We will presume for the time being that the current-strength would vary in accordance with the resistance of the substance and that by these means one might receive an idea as to the relative resistance of the substance. But it would be very inconvenient when speaking of the resistance of one substance to always have to refer to some other substance in order to form an idea as to its real resistance. It was therefore found necessary to select some unit resistance with which all other resistances could be measured.

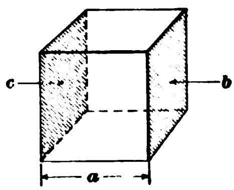


FIG. 3.

11. Definition of Ohm.—For this purpose, the resistance of a column of mercury of a given length and cross-sectional area has been chosen. The dimensions of the column expressed in inches are as follows: Length, 41.7323 inches; sectional area, .00155 square inch. When this unit was established, the dimensions were given in centimeters and square millimeters, the length being 106 centimeters and sectional area 1 square millimeter. In either case, the temperature of the column should be that of freezing water. This standard resistance is called the *legal ohm*, or simply **ohm**, and it is the unit resistance that is used in all measurements.

In cases where the resistance is very small and where it would be inconvenient to use fractions of an ohm, it is advantageous to use a smaller unit, such as a **microhm**, which is $\frac{1}{1000000}$ ohm. If, again, the resistance is very high, as with insulators, then it is customary to use the **megohm** as a unit; it is equal to 1,000,000 ohms.

12. Specific Resistance.—The electric resistance of 1 cubic inch of various materials are given in the following table. They are not expressed in ohms, but in microhms, the resistance of 1 cubic inch being so small that for some materials it amounts to even less than 1 microhm. These resistances are termed **specific resistances.** The table also gives the *relative resistances* of the same substances, when the resistance of silver has been selected as unit resistance.

TABLE I.

Name of Metal.	Resistance of 1 Cubic Inch at 0° C. Microhm.	Relative Resistance to Silver.
Silver, annealed	.5921	1.000
Copper, annealed	.6292	1.063
Silver, hard-drawn	.6433	1.086
Copper, hard-drawn	.6433	1.086
Gold, annealed	.8102	1.369
Gold, hard-drawn	.8247	1.393
Aluminum, annealed	1.1470	1.935
Zinc, compressed	2.2150	3.741
Platinum, annealed	3.5650	6.022
Iron, annealed	3.8250	6.460
Nickel, annealed	4.9070	8.285
Tin, compressed	5.2020	8.784
Lead, compressed	7.7280	13.050
German silver	8.2400	13.920
Antimony, compressed	13.9800	23.600
Mercury	37.1500	62.730
Bismuth, compressed	51.6500	87.230

We see from this table that it makes quite a difference what substances are selected for the material of an electric conductor. For instance, if a conductor of hard-drawn copper, having a specific resistance of .6433 microhm, be replaced by one of annealed iron, the specific resistance of which is 3.825 microhms, we find that the latter has a resistance about six times greater than that of the former.

It may be interesting at this point to give the relative resistances of the constituents of the human body. When the specific resistance of the muscles is considered as unit resistance, the other parts will have relative resistances as given in the following table compiled by Eckhardt:

Muscles	1.0
Nerves.	1.6 - 2.4
Cartilage	1.8 - 2.3
Tendons	1.8 - 2.5
Bone	16.0 - 22.0

13. Variation of Resistance With Length.—In determining the resistance of a conductor, various factors have to be considered. The resistance depends not only on the material of which it is made, but also on its length, cross-sectional area, and temperature.

If we add another cube behind that shown in Fig. 3, so that the electric current has to pass through two cubes, it will be easily understood that the resistance must be doubled, and that the resistance will continue to increase in direct proportion to the number of cubes in one series. We deduct from this the law that *the resistance of a conductor is directly proportional to its length.* For instance, if we have two pieces of copper wire of the same diameter, one 25 and the other 50 feet long, the latter would have twice the resistance of the former.

To find the resistance of a conductor when the resistance of a certain length of the conductor is known:

Let r_1 = known resistance;
r_2 = resistance that it is desired to find;
L_1 = the length, the resistance of which is known;
L_2 = the length, the resistance of which is to be found.

Then, since the resistance of a conductor is directly proportional to the length, we have

$$r_1 : r_2 = L_1 : L_2, \text{ or } r_2 = \frac{r_1 \times L_2}{L_1}.$$

NOTE.—The two lengths should always be reduced to the same unit.

EXAMPLE 1.—Find the resistance of 1 mile of copper wire, if the resistance of 10 feet of the same wire is .013 ohm.

SOLUTION.— r_1 = .013 ohm; L_1 = 10 feet; and L_2 = 5,280 feet. Therefore,

$$.013 : r_2 = 10 : 5{,}280, \text{ or } r_2 = \frac{.013 \times 5{,}280}{10} = 6{,}864 \text{ ohms. Ans.}$$

EXAMPLE 2.—Find the resistance of 11 inches of a German-silver wire, the resistance of 100 feet of the same wire being 2.4 ohms.

SOLUTION.— $r_1 = 2.4$ ohms; $L_1 = 100 \times 12 = 1{,}200$ inches; $L_2 = 11$. Therefore,

$$2.4 : r_2 = 1{,}200 : 11, \text{ or } r_2 = \frac{2.4 \times 11}{1{,}200} = .022 \text{ ohm. Ans.}$$

14. Variation of Resistance With Cross-Sectional Area.—The resistance of a conductor depends not alone on its length, but also on its cross-sectional area. If this area is *increased*, the resistance is *decreased*, and vice versa. We can understand that if a current of water flows through a narrow tube at the rate of 1 gallon per minute, the frictional resistance must be correspondingly reduced if we provide an additional tube so that only ½ gallon is compelled to pass through each tube per minute. If these two tubes are joined into one tube of a correspondingly increased diameter, the resistance now offered to the flow of 1 gallon per minute would be greatly reduced compared with the smaller tube previously used.

We may suppose that the cross-sectional area of an electric conductor influences the flow of an electric current in a similar manner and that *the resistance of a given conductor diminishes as its sectional area increases;* that is, *the resistance varies inversely as the sectional area.*

To find the resistance of a conductor when its sectional area is varied and other conditions remain unchanged:

Let r_1 = original resistance;
r_2 = required resistance;
a_1 = original sectional area;
a_2 = changed sectional area.

Since the resistance varies inversely as the sectional area,

$$r_1 : r_2 = a_2 : a_1, \text{ or } r_2 = \frac{r_1 a_1}{a_2}.$$

EXAMPLE 1.—The resistance of a conductor, the sectional area of which is .025 square inch, is .32 ohm; what would be the resistance of the conductor if its sectional area were increased to .125 square inch, other conditions remaining unchanged?

SOLUTION.— $r_1 = .32$ ohm; $a_1 = .025$ square inch; and $a_2 = .125$ square inch. Therefore,

$$.32 : r_2 = .125 : .025;$$

or, $$r_2 = \frac{.32 \times .025}{.125} = .064 \text{ ohm. Ans.}$$

EXAMPLE 2.—The sectional area of a conductor is .01 square inch, and its resistance is 1 ohm; if its sectional area is decreased to .001 square inch, and other conditions remain unchanged, what will be its resistance?

SOLUTION.— $r_1 = 1$ ohm; $a_1 = .01$ square inch; and $a_2 = .001$ square inch. Therefore,

$$1 : r_2 = .001 : .01;$$

or, $$r_2 = \frac{1 \times .01}{.001} = 10 \text{ ohms. Ans.}$$

Since the sectional area of a round conductor is proportional to the square of its diameter [sectional area = (diameter)^2 $\times$ .7854], it follows that the resistance of a round conductor is inversely proportional to the square of its diameter.

Let
r_1 = original resistance;
r_2 = required resistance;
d_1 = original diameter;
d_2 = changed diameter.

Then, $$r_1 : r_2 = d_2^2 : d_1^2, \text{ or } r_2 = \frac{r_1 d_1^2}{d_2^2}.$$

EXAMPLE 1.—The resistance of a round copper wire .12 inch in diameter is .64 ohm; find the resistance of the conductor when its diameter is increased to .24 inch, the other conditions remaining unchanged.

SOLUTION.— $r_1 = .64$ ohm; $d_1 = .12$ inch; and $d_2 = .24$ inch. Therefore,

$$.64 : r_2 = .24^2 : .12^2;$$

or, $$r_2 = \frac{.64 \times .12^2}{.24^2} = \frac{.64 \times .0144}{.0576} = .16 \text{ ohm. Ans.}$$

EXAMPLE 2.—The diameter of a round wire is .1 inch, and its resistance is 2 ohms; what would be its resistance if its diameter were decreased to .02 inch and the other conditions remain unchanged?

SOLUTION.— $r_1 = 2$ ohms; $d_1 = 1$ inch; and $d_2 = .02$ inch. Therefore,

$$2 : r_2 = .02^2 : .1^2;$$

or, $$r_2 = \frac{2 \times .1^2}{.02^2} = \frac{2 \times .01}{.0004} = 50 \text{ ohms. Ans.}$$

15. Variation of Resistance With Temperature. The resistance of a conductor is not the same at all temperatures. All conductors made of unalloyed metals increase in resistance by an increase in temperature. This increase amounts to about .4 per cent. for each degree Fahrenheit. For instance, if a copper conductor has a resistance of 1 ohm and its temperature has risen 1° F., its resistance will have increased to 1.004 ohms. By raising the temperature 100° F. its resistance would be 1.4 ohms.

Some metallic alloys used for resistance-coils suffer little increase in resistance when warm, and some of them, notably manganin, actually decrease in resistance. Liquids, carbon, and india-rubber decrease in resistance when heated.

16. Variability of Resistance.—One important feature of the *electric resistance* is that it remains constant during any variation in current-strength, provided the temperature of the conductor is unchanged. If, for instance, the resistance of a conductor is 20 ohms while a current of 5 amperes is passing through it, the resistance will still be 20 ohms whether the current-strength be increased to 100 amperes or lowered to 5 milliamperes.

This rule does not hold true for semiliquid conductors as the human tissues. Here it is found that after the current has been applied to the body for a certain length of time the resistance will *decrease* up to a certain point. For example, the resistance through a part of the body was at the start found to be 4,833 ohms, but after the current had been flowing for a period of 5 minutes the resistance had decreased to 2,070 ohms. In another instance, the resistance was 4,140 ohms, which fell to 1,610 ohms after 9 minutes.

It is not alone a prolonged application of the current that will decrease the resistance; an increase in current-strength will have a similar effect. For instance, at a current-strength of 2.75 milliamperes, the resistance was 1,330 ohms, which resistance fell to 1,145 ohms when the current was increased to 18.5 milliamperes.

THE VOLT.

17. Effect of Variation in Pressure.—We have so far considered the unit of quantity, the unit of current-strength, and the unit of resistance, respectively, the coulomb, the ampere, and the ohm. There remains a fourth fundamental unit, the **volt.**

In a conductor of a given resistance, it is possible to vary the current-strength within very wide limits by simply varying the electric pressure, or electromotive force. By doubling the pressure, we will also double the rate of flow. If, on the other hand, the pressure is constantly decreased, the current-strength will also decrease, so that when the pressure has fallen to zero the flow has ceased altogether. A conductor with a resistance of 1 ohm requires a definite and invariable pressure, or electromotive force, to send a current of 1 ampere through it. This pressure has been chosen as the unit of pressure and has been termed *1 volt.*

In electrotherapeutics, it is customary to consider 1 milliampere as the unit of current-strength, as one has to deal with small currents and high resistances. One volt would be the same in either case, but it may be more convenient for the physician to consider 1 volt as the pressure that will send a current of 1 milliampere through a resistance of 1,000 ohms.

18. Ohm's Law.—As the relation between the three units *volt, ampere,* and *ohm* forms the foundation for all calculations relating to current-strength, pressure, and resistance, it is important that this subject should be well understood. These three factors—amperage, voltage, and resistance—are so closely related to one another that we cannot change one without affecting one of the others. A few simple illustrations will explain this.

Suppose we have a conductor with 1 ohm resistance and exposed to the pressure of 1 volt. From what was said above, we know that the current-strength will then be 1 ampere. If we now increase the pressure to 2 volts, the current-strength will evidently increase to 2 amperes. Any increase in voltage will be followed by a corresponding increase in amperage. From this we may formulate the law that in a conductor of constant resistance the current-strength will vary at the same rate as the pressure varies. Or, stated more concisely, *in a conductor of constant resistance, the current-strength is directly proportional to the pressure.*

Let us next suppose that the pressure is constant and that the resistance is varied. It is clear from what has been said previously that the greater the resistance, the more pressure is required to force the current through the conductor. It follows from this that if we are unable to change the pressure, an increase in resistance will *diminish* the amperage. Again, selecting the conductor with 1 ohm resistance as an illustration, in which a pressure of 1 volt caused a flow at the rate of 1 ampere, let the resistance now be increased to 2 ohms. Evidently, the pressure of 1 volt is now unable to force a current of more than one-half the strength through the conductor and the amperage is therefore $\frac{1}{2}$ ampere. If we wish to increase this amperage, we must *reduce* the resistance. By making the latter $\frac{1}{2}$ ohm, the current will increase to 2 amperes. We conclude from this that an *increase in resistance* is followed by a *decrease in amperage*, provided the pressure remains constant.

In formulating a law that would apply to these conditions, we may say, that *in a conductor where the pressure is constant the current-strength varies inversely as the resistance.* In these combinations, we have assumed that only two factors varied at one time, it being more easy to trace the results; but it is obvious that all three may vary simultaneously. In that case, it would be somewhat inconvenient to find the final result, and it is therefore necessary to here explain the use of the so-called **Ohm's law,** named after Dr. G. S. Ohm, who first stated it, by means of which all problems of this nature may be easily solved. Ohm's law in its fundamental form is as follows:

The current varies directly as the electromotive force and inversely as the resistance of the circuit.

Stating this in the form of an equation, we would say

$$\text{current-strength} = \frac{\text{electromotive force}}{\text{resistance}}.$$

Or, if we let some symbol represent each of these factors, the equation would be: $C = \frac{E}{R}$. This is the usual form, in which

C = current-strength in amperes;
E = electromotive force in volts;
R = resistance in ohms.

The equation may also be used in the following form:

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}. \qquad (1)$$

Transforming the factors, the law may also read:

$$\text{ohms} = \frac{\text{volts}}{\text{amperes}}. \qquad (2)$$

or,

$$\text{volts} = \text{amperes} \times \text{ohms}. \qquad (3)$$

Equation (1) determines the strength of current that will flow in a conductor of a given resistance, when the pressure in volts is known.

EXAMPLE 1.—If the resistance of a part of the body is 1,200 ohms and the electric pressure through same is 60 volts, what will be the current-strength through same in milliamperes?

SOLUTION.—Applying equation (1), amperes $= \frac{\text{volts}}{\text{ohms}}$; hence, amperes $= \frac{60}{1,200} = .05$ ampere = 50 milliamperes. Ans.

NOTE.—For those who prefer to carry out their calculations without using decimals and wish to receive the answer directly in milliamperes, it will simplify matters to add three ciphers to the number of volts given. For instance, the above example would be solved as follows: amperes $= \frac{60,000}{1,200} = 50$ milliamperes. Ans.

EXAMPLE 2.—If the pressure through part of an arm is 15 volts and the resistance is 3,000 ohms, how many milliamperes will flow?

SOLUTION.—Amperes $= \frac{\text{volts}}{\text{ohms}} = \frac{15}{3,000} = .005$ ampere = 5 milliamperes. Ans.

Or directly in milliamperes: $\frac{15,000}{3,000} = 5$ milliamperes. Ans.

EXAMPLE 3.—The E. M. F. of a battery is 70 volts. It is found that a current of 25 milliamperes = .025 ampere passes through a patient; what is the resistance of the whole circuit?

SOLUTION.—According to equation (2), ohms $= \frac{\text{volts}}{\text{amperes}}$; hence, $\frac{70}{.025}$ = 2,800 ohms. Ans.

When the current-strength is indicated in milliamperes then the solution will be: $\frac{70,000}{25} = 2,800$ ohms. Ans.

NOTE.—To find how much pressure it will require to force a current through a given resistance, it will be necessary to use equation (3).

EXAMPLE 4.—How much pressure will it require to force a current of 50 milliamperes through a given part of the body, the resistance of which is 2,000 ohms?

SOLUTION.—Equation (3) states that volts = amperes × ohms; hence, .05 ampere × 2,000 ohms = 100 volts. Ans.

NOTE.—If it is preferred to give the current-strength in milliamperes direct, then 3 ciphers must be *deducted* from the number of volts given in the answer. For instance, 50 milliamperes × 2,000 ohms = 100,000 = 100 volts. Ans.

THE JOULE.

19. Unit of Work.—To set a current of water flowing, it is necessary to perform a certain amount of *work*. In Fig. 1 it was seen that the tank *B* would have to be raised to a certain height before the water would run, and it is easily seen that the position of the tank determines the pressure and strength of the current; that is to say, the greater the height, the greater the pressure. But to raise the tank requires an expenditure of work; that is, a given weight in pounds must be lifted through a distance of so many feet. In mechanics the amount of *work* done is determined by the distance through which the force acts. The unit of work is the **foot-pound**; it is the work done in lifting 1 pound through a vertical distance of 1 foot. Multiply the force in pounds by the distance in feet, and the product is the work in foot-pounds. When we lift a weight of 200 pounds through a vertical distance of 2 feet, we perform 400 foot-pounds of work; should we lift 400 pounds only 1 foot high, the result is still 400 foot-pounds, as before. In fact, it is immaterial what relation the two factors have to each other, so long as their product equals 400.

In sending a current of electricity through a conductor, work is done in a similar manner. We have seen that the unit quantity of electricity is a coulomb; if a pressure of 1 volt forces a quantity of electricity of 1 coulomb through a conductor, one *unit of work* has been expended, and this unit is called a **joule.** One joule is equivalent to .7373 foot-pound, or 1 foot-pound is equal to 1.356 joules.

Therefore, to find the amount of electrical work performed in joules, it is necessary to multiply the quantity of electricity in coulombs that has passed in the circuit by the pressure in volts.

Let $J =$ number of joules;
$E =$ pressure in volts;
$Q =$ number of coulombs.

Then, $$J = Q \times E.$$

EXAMPLE 1.—Find the amount of work done in joules when 30 coulombs of electricity is being forced through a conductor with a pressure of 10 volts.

SOLUTION.— $J = Q \times E = 30 \times 10 = 300$ joules. Ans.

NOTE.—It was shown that an ampere means 1 coulomb per second; when, therefore, the current-strength in amperes, the time during which the current flows, and the pressure are given, it is possible, from these items, to calculate the work in joules.

EXAMPLE 2.—Find the amount of work performed in joules when a current of 15 amperes flows for ½ hour under a pressure of 30 volts.

SOLUTION.—Reducing the time to seconds gives $30 \times 60 = 1{,}800$ seconds; 15 amperes mean 15 coulombs per second; therefore, $15 \times 1{,}800 = 27{,}000$ coulombs, multiplied by 30 volts, gives 810,000 joules. Ans.

THE WATT.

20. Power.—It must be borne in mind that, when speaking of work performed, *time* does not enter as an element. This is important, as many confusing statements result from speaking of time in connection with work. No mention was made of time when we were speaking of foot-pounds, coulombs, or joules, and purposely so, in order to avoid confusion. It makes no difference whether it takes 1 year or 1 minute to perform a given amount of work; the work in either case is of the same magnitude. Neither does it make any difference whether the quantity of electricity in coulombs forced through a circuit by a certain number of volts requires 1 minute or 1 hour to pass. In either case, the work performed is the same.

But when we speak of the *rate* of doing work, or *power*, that is an entirely different matter; a sharp distinction must be made between *work* and *power*. In daily life, these terms are used with the understanding that they mean the same thing; force, even, is supposed to be identical with power. Let it, therefore, be repeated that if a force acts through a certain distance it performs *work*, and that **power** is the *rate* at which this work is performed.

For instance, a boy may be able to do a certain amount of *work* in pumping water out of a well. If time does not have to be considered, he may be able to serve the purpose; but if it is necessary to get the water out in the shortest possible time, it is evident that a strong man is required. Why? Because he has more *power* at his disposal and is able to perform the work at a quicker rate. The rate at which two machines perform the same amount of work is proportional to the time expended. The unit of power in mechanics is *1 foot-pound per minute.*

21. Rule for Finding the Power.—The power of a machine may always be determined by *dividing the work it performs in foot-pounds by the time in minutes required to do the work.*

Let P = power in foot-pounds per minute;
F = force in pounds;
D = distance in feet;
T = time in minutes.

Then,
$$P = \frac{F \times D}{T}.$$

EXAMPLE.—If a machine performs 10,000 foot-pounds of work in 10 minutes, what is its power in foot-pounds per minute?

SOLUTION.—Applying the equation for power, we have

$$P = \frac{F \times D}{T} = \frac{10{,}000}{10} = 1{,}000 \text{ ft.-lb. per min.} \quad \text{Ans.}$$

22. Unit of Power.—We saw, in measuring work performed by electricity, that the joule was the unit used. When time has to be considered, it is customary to use the *second* only.

The unit of power used is therefore the *joule-per-second*, or the **watt.** As 1 joule is 1 coulomb × 1 volt, and as 1 watt is $\frac{1 \text{ coulomb}}{1 \text{ second}} \times 1$ volt, it follows that *1 watt* is *1 ampere × 1 volt*, since 1 ampere is 1 coulomb per second. Therefore, when 1 volt causes a current of 1 ampere to flow in a circuit, electrical work is performed at the rate of 1 *watt.*

Useful working formulas are as follows: 1 volt × 1 ampere = 1 watt, or the unit of electric power. 1 volt × 1 ampere × 1 second = 1 joule, or the unit of electric work.

23. Horsepower.—The units, *foot-pounds per minute* and *watts*, are too small when large machines are under consideration. A larger unit is therefore desirable, and for this purpose 33,000 foot-pounds per minute has been chosen and called **1 horsepower,** that being the power a strong horse is able to develop for a short time. It requires 746 watts to make 1 horsepower; that is, 746 watts is equal to 33,000 foot-pounds per minute.

In many cases it is preferable in place of a horsepower to use the *kilowatt* as a unit.

1 kilowatt = 1,000 watts.

Rule.—*To express the rate of doing electrical work in horsepower units, find the number of watts and divide the result by 746.*

Let W = power in watts;

H. P. = the horsepower.

Then,
$$\text{H. P.} = \frac{W}{746}.$$

EXAMPLE.—When a pressure of 50 volts causes a current of 30 amperes to pass through a circuit, (*a*) how much power is required in watts? (*b*) how much in horsepower?

SOLUTION.—(*a*) Since the power in watts is the product of the volts and amperes, we have 50 × 30 = 1,500 watts. Ans.

(*b*) From the formula H. P. = $\frac{W}{746}$, we get $\frac{1,500}{746}$ = 2.01 H. P. Ans.

24. Unit Abbreviations.—When using Ohm's law, it is customary, for the sake of convenience, to use the terms volts, ohms, and amperes in an abbreviated form; thus, volts, pressure, or electromotive force are represented by the letter E; ohms, or resistance, by the letter R; and amperes, current-strength, or current-volume, by C. In the following pages, Ohm's law will be represented by these letters, and in its three variations will appear as

$$C = \frac{E}{R};\ R = \frac{E}{C};\ \text{and } E = R \times C.$$

Power in watts will be $W = E \times C$; but can also be expressed by the two following equations, viz.:

$$W = C^2 \times R;\ \text{or } W = \frac{E^2}{R}.$$

EXAMPLE 1.—If a current of 50 amperes is forced through a resistance of 40 ohms, what power is expended?

SOLUTION.—Applying the formula $W = C^2 \times R$, we have
$W = 50 \times 50 \times 40 = 100{,}000$ watts, or 134.05 H. P. Ans.

EXAMPLE 2.—If 3,000 volts pressure is supplied to a circuit of 6 ohms resistance, what power is needed in horsepower?

SOLUTION.—From the formula $W = \frac{E^2}{R}$, we have

$$W = \frac{3{,}000 \times 3{,}000}{6} = \frac{9{,}000{,}000}{6}.$$

Dividing by 746, to reduce to horsepower, we have

$$\frac{9{,}000{,}000}{6 \times 746} = 2{,}011 \text{ H. P., nearly. Ans.}$$

PRODUCTION OF ELECTROMOTIVE FORCE.

25. Devices for Creating E. M. F.—We have seen that certain conditions have to be fulfilled before a current of electricity is established. We know that it needs the creation of an E. M. F., a conductor to transfer the electricity from one place to another, and further, that this conductor must be of a certain material and cross-sectional area to fulfil its purpose in a satisfactory manner. It will now be necessary to describe the means for producing an E. M. F.

There are various devices for creating E. M. F., but all of them are not of the same importance. Some are rarely used for electrical purposes, and never in therapeutics. It will not be necessary, therefore, to describe them in these pages, and they will be mentioned only as possible sources. Their classification may be as follows:

1. Those producing an E. M. F., by means of chemical action, such as voltaic, or primary, or galvanic cells and secondary cells.

2. Those producing an E. M. F., by means of mechanical energy; for instance, dynamo-electric machines and electrostatic induction-machines.

3. Those utilizing radiant energy, as light and heat, for the production of an E. M. F.; as, for example, the thermo-electric cell.

4. Animals and plants. Instances of animals are the torpedo and gymnotus. The roots and interior parts of trees are found to be negatively, and flowers, smaller branches, and fruits to be positively, electrified.

The first two classes only need be considered, and as the second class cannot be understood until after the subject of electro-magnetism has been studied, we will at present limit our discussion to the first class alone.

PRIMARY AND SECONDARY CELLS.

26. Simple Voltaic Cell.—If a jar is filled about three-fourths full of water to which 5 per cent. of sulfuric acid has been added, and a strip of zinc is partially inserted in this solution, it will be found that the zinc is at once covered with bubbles of some gas, which eventually release themselves and come to the surface. At the same time, it will be noticed that the zinc is eaten away and that it grows thinner and thinner. If a strip of copper is also inserted into the solution without touching the zinc, no difference is noticed. Now let the two strips touch each other outside the liquid and a great change will be seen at once. A large number of bubbles is now also formed around the copper, from which they also rise to the surface, while the zinc continues to develop gas as before. This gas, when collected either from the copper or zinc plate, will be found to be the same and to be hydrogen.

If the zinc is removed from the liquid and some mercury rubbed on its surface by means of a rag, the mercury will combine with the zinc and form an amalgam. When it is again replaced in the liquid, it is found that no gas bubbles will be formed on it but solely on the copper.

We have here to do with an elementary **voltaic cell** in which the copper and zinc strips constitute the two *voltaic elements;* when taken collectively they are known as a **voltaic couple.** The said solution, or any other compound chemical substance in solution which undergoes a decomposition when traversed by an electric current, is called an **electrolyte.**

A simple voltaic, or galvanic, cell of this kind is illustrated by means of Fig. 4, in which A is a glass jar and Z and C the two elements, respectively, zinc and copper, inserted in acidulated water. The two elements are here shown separated and each has attached to its upper end a short length of wire that can be connected to each other or to an ammeter or any other instrument that will indicate the presence of an electric current. Such an instrument will show that a current of electricity is constantly flowing from the copper to the zinc, as indicated by the arrow in the figure.

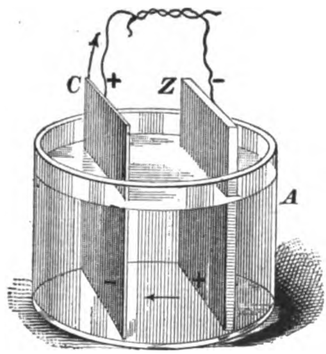


FIG. 4.

A **voltaic battery** is a number of simple voltaic cells properly joined together.

The **terminals** of a cell are the parts of the plates outside of the electrolyte.

It should be remembered that the polarity of that end of the plate or voltaic element which is acted on by the electrolyte is always of opposite sign to its terminal. For instance, in the case of the zinc-and-copper couple, the terminal of the zinc plate, or that part outside of the electrolyte, would be spoken of as the *negative terminal,* while that part of the copper plate outside the electrolyte would be spoken of as the *positive* *terminal.* When mention is made of the positive or negative pole of a cell, reference is always made to the *exposed parts* of the elements, and no attention is paid to the submerged parts. The symbols + and — refer to the parts of the elements not contained in the electrolyte, and are always of an opposite sign to the parts submerged in the electrolyte.

27. Local Action.—It must be remembered that a current will be established between the elements of a voltaic cell only when they are in direct contact or connected by means of an outside conductor. We saw that wherever a difference of potential exists there is a tendency to equalization by a flow of electricity from the higher potential to the lower. It follows from this that after a time the potential of both elements would be the same and no current would flow; but, fortunately, chemical action sets in as soon as the potential difference is lowered, and immediately brings it up to its initial value. We should suppose from this that on disconnecting the exterior conductor, that is, on opening the circuit, all chemical action would cease, because no tendency existed to lower the potential difference. Such would be the case if the zinc were perfectly pure, but, as commercial zinc is ordinarily mixed with particles of iron, arsenic, and other metals, the conditions are altered. By consulting the electromotive series, which is given later, it is observed that iron is half way between zinc and copper, and that a difference of potential will be produced between them which, though not as high as in the former case, will be sufficient to start a current. In other words, there will be a **local action**; that is to say, currents flow between various places on the same plate. As these currents do not manifest themselves outside the cell, they will evidently waste the zinc to no purpose, both when the circuit is open and when it is closed. This explains why the zinc plate in Fig. 4 is attacked by the acid in the absence of the copper plate. There is then a local action all over the plate, caused by the various impurities existing in the zinc.

28. Amalgamation.—To prevent this local action, the zinc is submitted to a process called **amalgamation.** By this means the iron is separated from the zinc and made harmless. Before amalgamating the zinc it is first dipped into an acid bath, which removes all impurities from the surface; then a little mercury is poured over it and rubbed into the surface with a rag or a piece of galvanized iron. When finished, the surface should be as bright as silver. Another way to amalgamate the zinc is to immerse it in an acid solution of mercuric nitrate. The zinc unites with the mercury, and the result, by either method, is that the whole surface is covered with a pasty amalgam. The iron does not participate in this combination, but remains undissolved and appears on the surface of the amalgam as small particles, and, as soon as the cell begins its action, they are carried away by the hydrogen bubbles. It is a peculiarity of this amalgam that it does not leave the zinc when the latter dissolves, but immediately attaches itself to fresh portions of the same. The surface will therefore always appear bright and clean. If a hissing noise is heard when the zinc is placed in the electrolyte, it signifies that the zinc requires reamalgamation.

29. Electromotive Series.—In any voltaic cell, the element that is acted on by the electrolyte will always be the generating-plate, and its terminal is always negative. The following list of voltaic elements compose the **electromotive series:**

Contact in Air.

+ Zinc	Antimony
Cadmium	Copper
Tin	Silver
Hydrogen	Gold
Lead	Platinum
Iron	Carbon
Nickel	— Oxygen
Bismuth	

Any metal in this list is electropositive to every other below it, and electronegative to every other above it.

Any two of these metals form a voltaic couple, and produce a difference of potential when submerged in saline or acidulated water, the one standing first on the list being the generating-plate, and the other the collecting-plate. For example, if nickel and carbon are used, the nickel will be acted on by the liquid and will form the generating-plate; but if nickel and zinc are used, the zinc will be acted on by the liquid and will form the generating-plate.

The farther apart the elements stand in the above list, the greater will be their difference of potential. For example, the difference of potential developed between zinc and carbon is much greater than that developed between zinc and nickel; in fact, the difference of potential developed between zinc and carbon is equal to the difference of potential developed between zinc and nickel plus that developed between nickel and carbon. This may be summed up in the following law, as first stated by Volta:

The difference of potential developed between any of these metals is equal to the sum of the difference of potentials of all those intervening.

In the simple cell illustrated in Fig. 4, we have seen that zinc was the element acted on by the electrolyte, and this element is called the generating-plate. Strictly speaking, the surface of contact between the liquid and the metal is the place of action, and would more properly be called the generating-plate.

The other element—in this instance, copper—is called the collecting-plate, and serves merely as a means of connecting the external circuit to the electrolyte. In some cells, the chemical action takes place between two different liquids, in which case whatever solid conducting-bodies are used act merely as connectors or terminals.

In therapeutics, the term **anode** is used simply to indicate the positive terminal, and **cathode** to indicate the negative terminal.

30. The Electrolyte.—Before attempting to explain the chemical action going on in a simple cell, the passage of a current through a fluid, such as an electrolyte, will have to be considered. Fluids do not conduct an electric current in the same manner as solids; in the latter, it may be supposed that the electricity flows *from* one atom to another, the latter remaining stationary. When the electric current goes through a fluid, it travels *with* the atoms, and each of the latter is supposed to carry with it a certain amount of electricity, that is, an *electric charge.* The latter may be of two kinds, *positive* and *negative.* A charge is said to be **positive** when it is of such a nature that electricity will flow from it to some other atom or substance that is either neutral or negative. Again, a charge is said to be **negative** when electricity will flow *toward* it, either from a neutral or a positive atom or substance. These positive and negative charges mutually attract each other, and, when united, they both become neutral if possessed of charges that contain equal amounts of electricity; if not, the surplus will be equally divided between both.

It is now generally supposed that all atoms are possessed of electric charges, varying in amount and being either positive or negative. It is supposed that the *chemical affinities* that the chemist has to overcome in order to affect new combinations is nothing but the attraction between positive and negative charges.

It is further supposed that when a compound chemical substance is dissolved in water, the latter seems to have the effect of giving the constituent atoms of a molecule a certain freedom of action, thus enabling them, by means of some small outside directing force, to overcome the forces that held the atoms together and previously made them appear electrically neutral.

31. Interaction Between the Electrolyte and the Elements.—Let us now apply these theories to the action of the voltaic cell. The molecules of the sulfuric acid consist of two groups, one, the sulfion SO_4 is electronegative, and the other, the hydrogen, electropositive. When the two elements of zinc and copper are inserted in the electrolyte, both elements seek to attract the sulfion groups, but the zinc with its greater tendency to oxidation has the stronger attraction of the two, with the result that the negative oxygen moves toward the zinc, leaving the hydrogen free to seek the copper. The sulfion unites with the zinc, producing *sulfate of zinc*, while the hydrogen collects at the copper plate, some of it escaping and rising to the surface. When it is stated that the zinc attracts the oxygen, it should not be understood to mean that this range of attraction extends throughout the electrolyte. We must rather suppose that the distance through which it acts is extremely minute. This range, called the *molecular range*, is estimated to be about $\frac{1}{10000000}$ part of a millimeter. When the oxygen atoms inside this range have been attracted, other atoms in the adjoining layers will immediately replace them by diffusion. We can therefore imagine a constant procession of oxygen atoms toward the zinc element and a similar motion of hydrogen toward the copper element.

As the oxygen and hydrogen atoms were supposed to be in possession of negative and positive charges, respectively, the first would deposit their negative charges on the zinc and the latter their positive charges on the copper. This action would continue until the pressure, or potential, of the greater charges on the zinc and copper had increased to such an extent as to equal that of the individual atoms. The latter would then be unable to deliver their charges any more and the action would stop. But if the two elements are connected externally to the electrolyte, with an electric conductor, then an electric current would be established through the latter and their surplus charges would constantly flow through this conductor and neutralize each other.

32. Continuous Current.—The charges delivered to the elements follow one another with great rapidity, so rapidly, in fact, that it is impossible to distinguish any momentary interruption, and the action seems to be absolutely *continuous*. The equalizing flow of electricity that is constantly passing from one plate to the other through the external conductor is known as a **direct current,** which may or may not be continuous. Consequently, a direct current becomes continuous when the difference of potential is constantly maintained, and when no mechanical device is employed to interrupt it. This difference of potential or electromotive force, which is the direct cause of the electric current through the cell, does not depend on the shape or size of the elements employed. It depends primarily on the materials used, but is also somewhat affected by the density of the electrolyte and the surface conditions of the elements.

33. Polarization.—The action of the cell would continue until either the electrolyte were exhausted by being replaced by sulfate of zinc or the zinc itself had been wasted. In a simple voltaic cell, there are still other causes that may stop all action long before the electrolyte is exhausted. This is caused by the action of the hydrogen. When the latter passes to the copper element, it cannot combine chemically with the copper as the oxygen does with the zinc. The hydrogen atoms will therefore, after they have given up their electric charges, remain at the copper element in a nascent state. If the hydrogen would at once rise to the surface, any further trouble would be prevented, but they adhere to a large extent to the copper element. The consequences of this action are various. One is that the copper element, after a certain length of time, will be covered with a film of hydrogen, and the latter being a poor conductor will greatly increase the resistance to the passage of the current. Then, again, hydrogen being electropositive, practically an electronegative element with an electropositive coating is had. Both the zinc and the copper would then be electropositive and their tendency to separate the atoms would be materially diminished. In this condition, the hydrogen would seek to reunite with the oxygen from which it was separated and send a current in the opposite direction. When the action of the cell has arrived at the point that the collection of hydrogen on the copper plate prevents, or greatly opposes any further action, the cell is said to be **polarized**. To bring the cell back again into its maximum activity, the hydrogen must be removed. Any agent that will serve this purpose is called a **depolarizer**.

34. Depolarization of Cells. — Various mechanical devices for depolarizing cells have been used; the collecting-plate has been arranged to be agitated in the liquid, or to be entirely removed from the liquid at intervals; and the collecting-plate, or in some instances both plates, have been made in the form of disks, dipping for about half their diameter into the electrolyte. On rotating the disks, the hydrogen is prevented from forming on the collecting-plate by its motion. Again, the liquid itself may be kept in constant circulation by various means. Sometimes the surface of the collecting-plate is roughened and provided with small projections on which the gas collects more freely and with more facility for detaching itself, and in the form of bubbles to rise to the surface. But, as none of these devices prevent depolarization altogether, they are commercially of little value, especially as chemical depolarizers are much more convenient.

35. Chemical Depolarization.—Depolarization by *chemical means* may be accomplished by surrounding the collecting-plate with a solid or liquid with which the nascent hydrogen may combine. This combination usually disposes of the gas, and prevents the bad effects due to its deposit on the collecting-plate. Under these circumstances, the compound formed at the collecting-plate is usually water, the depolarizer being generally a substance rich in oxygen, with which the hydrogen combines. This water has the effect of diluting the electrolyte already weakened by the combination with the generating-plate; but, by properly selecting the depolarizer with reference to the electrolyte, the chemical combination at the collecting-plate may be such that it will, either directly or by further combination, replace that part of the electrolyte which has been combined with the generating-plate. By this means, the electrolyte will be kept at the same strength and composition throughout the life of the generating-plate or of the depolarizer.

36. Rate of Depolarization.—The *rate* at which any depolarizer will perform its function depends on many conditions. *No depolarizer will keep the E. M. F. of a cell constant for all currents;* for, after a certain limiting current has been reached—the limit depending on the sizes of the various parts of the cell—the formation of the free element of the electrolyte is more rapid than its absorption by or recombination with the depolarizer, and the surplus gas will then collect on the collecting-plate. In the case of depolarizers that, by the formation of water, dilute the electrolyte, the E. M. F. is reduced by continued use of the cell, even if the current output be small. These facts should be remembered in dealing with the various depolarizers.

37. Primary Batteries as Sources of Electrical Energy.—Primary batteries, as sources of electrical energy, are used principally in those cases where the use of the current is intermittent, such as for ringing bells, for lighting gas, etc., or where a small but steady current is required for long periods of time, as in electrotherapeutics, in telegraphy, in telephony, for laboratory and for testing purposes. Their general use on a large scale as sources of electrical energy for lighting or for power purposes is precluded, at least at present, by the comparatively great cost of the material consumed, and the expense of insulation and maintenance. For example, the bichromate battery is about the cheapest in point of cost of materials consumed, and in this the materials alone would cost about 28 cents per horsepower per hour when used on a large scale. When the electrical energy is produced by means of dynamos, the cost per horsepower per hour is ordinarily about 5 or 6 cents, and in many cases much less. The cost of material in the silver-chlorid battery is about $1.35 per horsepower per hour. This high cost of the power does not, however, prevent batteries from being largely used for the purposes previously outlined, and their practical application is an important part of electrotherapeutics.

38. The Voltameter.—Reference was had in Art. **6** to the **voltameter** as an apparatus that would enable us to obtain an idea as to the amount of work 1 coulomb of electricity would be able to do when sent through a circuit by a given electric pressure. The voltameter is in reality nothing but a voltaic cell in which the action is reversed, on which action also the storage-batteries or accumulators are based. It was seen that in a voltaic cell the active principle was the superior attraction between the zinc and the oxygen as compared with that between zinc and hydrogen. It is clear that if both elements in the cell were either zinc or copper, no action would take place and the cell would be dead. But this difficulty may be overcome if by some exterior means an attraction between the elements and the component parts of the electrolyte is created. Suppose, for instance, that one of the elements is connected with the positive pole of some source of an electric current and the other with the negative pole; one of the elements will then be positive and the other negative. As the hydrogen and oxygen atoms of the electrolyte are in an unsettled condition, ready to go wherever a directing force will guide them, it is clear that the positive hydrogen atoms will seek the negative element and the negative oxygen atoms the positive element. A procession of hydrogen atoms will pass in one direction and oxygen atoms in another. As soon as they meet either of the two electrodes, their motion stops and there will, therefore, on one of the electrodes, be a collection of oxygen, and on the other hydrogen.

The zinc has a strong affinity for oxygen and it will again unite with the sulfion group and produce sulfate of zinc. To obviate this and retain the pure oxygen, the negative electrode is made of a metal that is nearly neutral toward the oxygen, as for instance, platinum. The liberated oxygen will then not enter into any combination, but remain in a gaseous state and either rise to the surface or adhere to the platinum.

It requires a certain pressure, or E. M. F., to effect this separation of oxygen and hydrogen atoms, below which no results can be obtained. The pressure must at least be 1.49 volts. After the atoms have been separated and are in the nascent state, they have a tendency to reunite; the electrodes are said to be **polarized.** If the electrodes are disconnected from the electric source and connected with each other, a current will flow through them in the opposite direction for a short time, having at the start a pressure of 1.49 volts. This current is called a *polarization current* and is the one on which the action of storage-batteries is based.

39. Electrolysis.—This process, by means of which acidulated water and other solutions may be decomposed by electrical means, is called **electrolysis,** meaning electric analysis. The separated atoms are called **ions.** The electrode that sends the electric current *into* the fluid is an *anode*, and that electrode which conducts the current *away* from the fluid or electrolyte is the *cathode.* Atoms that travel toward the anode and assemble there are **anions;** the atoms congregating at the cathode are **cations.** It should be remembered that the anions traveling toward the positive electrode—the anode—have negative charges and that is the reason an attraction takes place between them. Likewise, the cations are positively charged and therefore seek to join the negative electrode—the cathode. The amount of gas deposited on the electrodes of a voltameter by 1 coulomb, that is, by 1 ampere per second, is .00001043 gram of hydrogen and .00008285 gram of oxygen. In volume, the hydrogen amounts to twice that of the oxygen.

CELLS.

40. Classification.—The various kinds of voltaic cells may be divided into classes as follows:

1. *Cells in Which There Is No Depolarizer.*—These are the simplest form of cells, but, because they polarize rapidly, cells of this class, commonly called *open-circuit* cells, are used only for intermittent work.

2. *Cells With a Depolarizing Electrolyte.*—In this class of cells, the electrolyte is of such a nature that either no hydrogen is formed or the liquid contains a substance with which the hydrogen unites. As this action takes place mainly at the collecting-plate, there is little distinction, so far as action goes, between this latter type of Class 2 and the following class.

3. *Cells With a Liquid Depolarizer.*—In this class of cells, the collecting-plate is surrounded by a depolarizing liquid that is, by mechanical means, prevented from mixing with the electrolyte. The method that is usually employed is to separate the two liquids by a porous partition, which allows of their electrical contact without mechanical mixture, if their respective specific gravities are nearly the same. If the latter differ materially, gravity will keep the two liquids apart, one being above the other in the containing vessel.

4. *Cells With a Solid Depolarizer—Dry Cells.*—In many respects, this class is identical in action with Class 3, the only difference being that the depolarizer is a solid instead of a liquid. If the solid depolarizer is granular, or in the form of powder, it is often necessary to employ a porous partition between the collecting-plate surrounded by the depolarizer and the electrolyte. This is merely to keep the depolarizer in place, and may be dispensed with if the depolarizer is in the form of a paste or solid body fastened upon the collecting-plate. In fact, the depolarizer itself frequently forms the collecting-plate when it is a solid conducting material, the office of the collecting-plate being primarily to establish a connection between the electrolyte and the external circuit.

Ordinarily, cells are classed as *single-fluid* and *two-fluid cells;* but, as such a classification has little reference to this principle of operation, it will not be used here. All the different kinds of cells will not be described, and reference will only be made to those that have shown themselves most suitable for the purpose of electrotherapeutics.

CELLS WITH NO DEPOLARIZER.

41. The Volta Type.—In this class are included cells of the **Volta type,** illustrated in Fig. 4. In place of copper as a collecting-plate, many other elements have been used, notably in the Smee cell, using platinum or platinized silver, and cells of various other makes, in which the collecting-plate is of iron. The available E. M. F. of the Smee cell is hardly more than .5 volt. It was found that copper could be advantageously replaced by porous carbon. The E. M. F. of the porous-carbon cell is about 1.35 volts. To prevent the electrolyte from being too quickly exhausted, there is sometimes placed in the cell a porous cup filled with strong sulfuric acid. As the dilute acid outside the porous cup becomes weaker, the stronger acid oozes through the sides of the porous cup and maintains the strength of the electrolyte.

In all the cells of this type, the carbon is made as porous as possible and of such shape that the surface exposed to the liquid is very large compared with the surface of the zinc.

Thus, the average area of the internal circuit of the cell is made large, and at the same time advantage is taken of the slight depolarization that occurs with a porous carbon of large surface. Porous carbon absorbs oxygen from the air, and some of the evolved hydrogen combines with this, thereby diminishing the tendency to polarization.

CELLS WITH A DEPOLARIZING ELECTROLYTE.

42. Bichromate Cells.—The best known cells of this type are the bichromate cells. Twenty of these cells form the best portable battery having a liquid electrolyte. These consist of a zinc-carbon couple, with an electrolyte composed of a solution of dilute sulfuric acid, mixed with a proportion of the *bichromate salts* of some metal, usually potassium. The purpose of the bichromate salt is to act as a depolarizer, which it does very satisfactorily, on account of the large quantity of oxygen that it contains. When, therefore, the hydrogen is liberated by the decomposition of the electrolyte, it unites immediately with the bichromate salt, forming water and a new salt known as *chrome alum*, which forms in crystals of a purplish color. If the salt of sodium is used instead of the salt of potassium, there is no formation of *chrome alum*, and the working capacity of the cell is therefore greater. The result of this combination is a high E. M. F. of about 2 volts. By the action of the acid in the electrolyte on the bichromate of potassium, chromic acid is formed. It has been proved that pure zinc is 175 times more soluble in acid containing a little chromic acid than in pure dilute acid. The zinc will be attacked by the acid whether any current is flowing or not—hence the importance of arranging the zinc in such a manner that it may be lifted from the liquid when not in use.

43. The Grenet Cell.—A familiar type of bichromate cell is the **Grenet cell,** shown in Fig. 5. It consists of a bottle-shaped jar with a hard-rubber or porcelain cover from which two flat carbon plates *C*, *C* are suspended, parallel to and a short distance from each other. Between them hangs a zinc plate *Z*, supported by a sliding-rod *R*, which may be drawn up until the zinc is entirely out of the liquid. The rod is held in any position by the thumbscrew *T*. On top of the brass rod is a binding-post B_1, the other terminal of the cell being the binding-post *B* connected to the two carbon plates *C*, *C*. The electrolyte is composed of 3 parts of potassium bichromate dissolved in 18 parts of water, to which is added 4 parts of sulfuric acid. The E. M. F. of the cell is 1.92 to 2 volts.

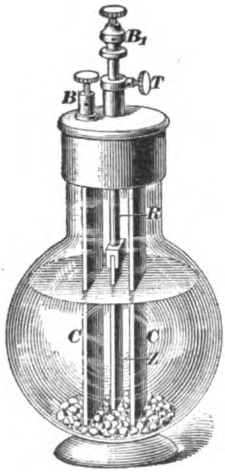


FIG 5.

44. Plunge-Batteries. — Cells of the bichromate type are often united to form what is called a **plunge-battery.** These are usually built with several cells, the various elements being connected in series to give an E. M. F. of 6 to 10 or more volts. All the elements are simultaneously raised out of or lowered into the liquid by a lever or windlass arrangement, as shown in

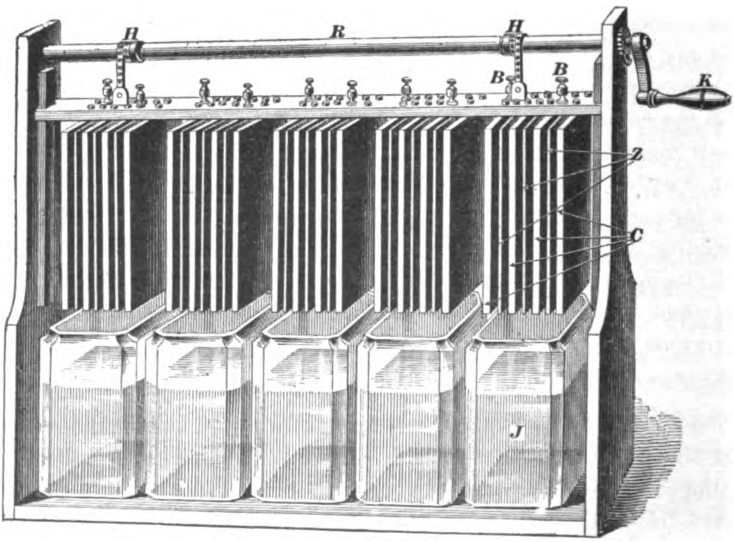


FIG. 6.

Fig. 6, which represents a battery of five cells, all alike. The elements are zinc and carbon, there being three plates of zinc *Z*, and four of carbon *C*, in each cell. All the plates are suspended from a wooden cross-bar, which is supported by means of the chains *H*, *H* from the rod *R*. By turning the crank *K* on the rod, the plates may be raised or lowered into the jars *J*. Each cell is provided with two binding-posts *B*, *B*, connected, respectively, with the carbon and zinc plates. The cells may therefore be arranged in various combinations.

To this class belongs also the **Pabst cell,** in which wrought iron and carbon are used as elements, and a solution of ferric chlorid as the electrolyte. The ferric chlorid is decomposed into ferrous chlorid and free chlorin, the latter uniting with the iron element. There is no polarization, as the liquid regenerates itself by absorbing oxygen from the air. It is very constant, but of low E. M. F., about .78 volt.

CELLS WITH A LIQUID DEPOLARIZER.

45. Nitric Acid as a Depolarizer.—Nitric acid HNO_3, being rich in oxygen, is largely used as a depolarizing liquid in this class of cells. Its use is objectionable from the fact that, when deprived of a part of its oxygen, it gives off a gas, nitric oxid, which, on combining with the oxygen of air, becomes nitrogen peroxid, a disagreeable and even dangerous corrosive gas; consequently, the best of ventilation is essential where cells with this depolarizer are used.

46. Grove and Bunsen Cells.—The principal cells using this depolarizer are the **Grove** and the **Bunsen cells,** and some of their derivatives. In the Grove cell, the positive element is zinc; the negative, platinum. The platinum element is placed inside a porous cup and surrounded with nitric acid diluted with water. The E. M. F. of the Grove cell is 1.9 volts at ordinary temperatures. The Grove cell is a very old type, and has been made in many forms. The expense of the platinum element led to the adoption of the Bunsen cell, in which carbon is substituted for platinum. By using commercial nitric acid, specific gravity about 1.33, the E. M. F. may be increased to 1.96 volts. About .35 volt is due to the action of the depolarizer. These cells are objectionable because of their odor, and must be situated in a place where this is not objectionable. They are useful for charging small accumulators.

47. Electropoion Fluid.—Another important type of this class of cell is the **bichromate cell,** in which the bichromate solution is not mixed with the electrolyte, but separated from it by a porous partition, with the effect that the zinc is not seriously attacked on open circuit. As to the E. M. F., chemical action, etc., this type is not sensibly different from the bichromate cell described above. The bichromate solution is usually, with the collecting-plate, placed in the outer vessel, the zinc and exciting liquid being inside the porous cup. The exciting liquid is usually dilute sulfuric acid having a specific gravity of about 1.10. The depolarizing liquid is ordinarily of the composition given in Art. **43.** Under the name *electropoion fluid*, a bichromate mixture is prepared by dealers (all parts by weight) as follows: 2 parts of sulfuric acid is mixed with 4 parts of water; in another vessel, 1 part of potassium bichromate is dissolved in 3 parts of boiling water, and, while hot, is mixed with the liquid first prepared. This liquid, when cold and more or less diluted, is suitable for use in most bichromate cells.

Bichromate cells are often constructed in which the liquids employed have such a difference in their specific gravities that they may be placed one above the other in the cell, no porous partition being required to keep them from mixing.

48. The Partz Cell.—The **Partz cell,** one form of which is illustrated in Fig. 7, is an example. This cell is a bichromate cell in which a solution of sodium chlorid or magnesium sulfate constitutes the electrolyte and surrounds the zinc *Z*; a bichromate solution, which acts as a depolarizer, surrounds the carbon plate *C*. The depolarizer, having a higher specific gravity than the electrolyte, remains at the bottom of the jar, and the two liquids are thus kept separate. To keep up the strength of the depolarizer, a glass tube *T* is suspended in the cell, having a small opening below the normal level of the bichromate solution. This tube is filled from time to time with crystals of what the manufacturers call *sulfochromic salt*, which is formed by the action of sulfuric acid on some bichromate solution, and when dissolved in water gives the same results as the electropoion fluid. The depolarizer, as it becomes weakened by use, is replenished by crystals in the tube *T*.

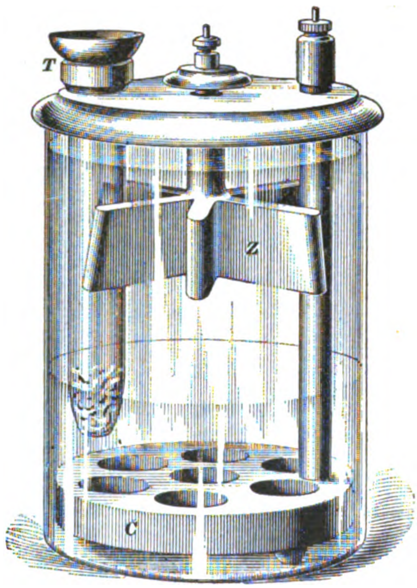


FIG. 7.

With the cell shown, which employs a 6″ × 8″ jar, the internal resistance is about 1 ohm with a solution of magnesium sulfate, and about .5 ohm with a solution of sodium chlorid, the E. M. F. being the same, 1.9 to 2 volts, in either case. This cell is useful for either open- or closed-circuit work, as the depolarization is very complete; at the same time the local action on open circuit is almost imperceptible. The chromealum solution that forms, being heavier than the bichromate solution, descends to the lower part of the cell, so that the crystals form beneath the carbon plate, which is slightly raised from the bottom of the jar; consequently, the formation of these crystals does not appreciably increase the internal resistance of the cell.

49. The Daniell Cell.—Another cell belonging to this class is the **Daniell,** a variation of which is illustrated in Fig. 8; it is here shown in the familiar form known as the *gravity*, or *crowfoot*, *cell.* The zinc *Z*, from the shape of which the cell has received its name, hangs from the edge of the glass jar; the copper *C* is connected to the external circuit by the wire *W*, covered with an insulating material on those parts submerged in the liquid. When the cell is set up, the copper plate is surrounded with crystals of cupric sulfate, until it is completely covered. The standard form of this cell is of the following dimensions: The jar is 6 inches in diameter, and is 8 inches high. The copper, made from three pieces of thin sheet copper 2 inches wide and 6 inches long, is riveted together in the middle; the outside pieces are then spread out, giving the copper the shape of a six-pointed star. A piece of No. 16 insulated copper wire is riveted to the middle strip. The zinc is in the shape shown, and weighs 3 pounds. About 2 pounds of cupric-sulfate crystals are required to charge the cell. The average internal resistance of a gravity cell of this size is about .5 ohm, and its E. M. F. is the same as the other forms of Daniell cell, 1.07 volts.

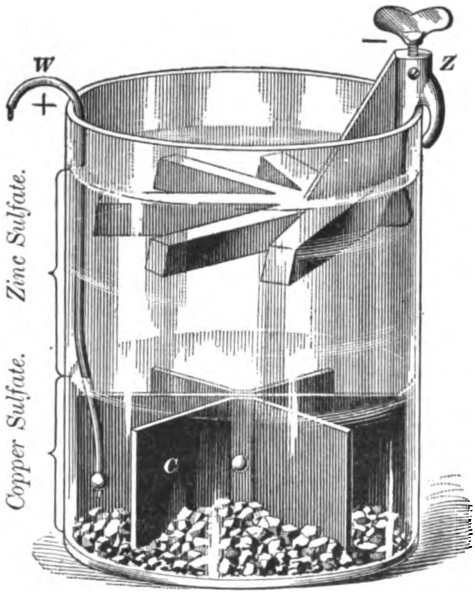


FIG. 8.

The maintenance of this type of cell is simple, it being necessary to renew the supply of cupric-sulfate crystals only when the solution becomes weak, which fact is indicated by the fall of the blue-colored liquid below the top of the copper plate. In addition to this, the density of the zinc-sulfate solution should be occasionally measured with a hydrometer, and if too dense (above 1.15 Sp. Gr.) a portion should be removed and replaced by water.

50. D'Infreville Zinc.—To avoid waste, various forms of the zinc element have been suggested in place of the crow-foot pattern; one form, in which there is no waste whatever, is the **D'Infreville wasteless zinc.** This zinc is cast with a conical lug *C* on top (see Fig. 9) and a corresponding cavity in the under side of the zinc. When the zinc is nearly consumed, it is removed from its support, and the lug *C* inserted in the cavity of a new zinc, which is then placed in its support. The old zinc is thus placed underneath and is entirely consumed. The figure shows a cross-section of this form of zinc, the new zinc *A* resting on a partly consumed zinc *B* with the stub of a third zinc *C* beneath. The use of the Daniell cell in medical practice is limited chiefly to the charging of accumulators.

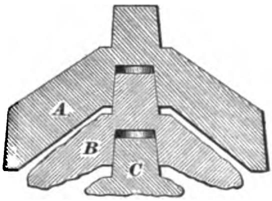


FIG. 9.

CELLS WITH A SOLID DEPOLARIZER.

51. The depolarizers that are used in this class of cells are generally substances containing a large proportion of oxygen, with which the nascent hydrogen unites, forming water. Solid depolarizers, like liquid depolarizers, are chosen on account of the large quantity of oxygen that they contain. The balance of the depolarizer is sometimes dissolved in this water, but it more often remains at the collecting-plate in the form of a solid, the water serving merely to dilute the electrolyte. In case the depolarizer is dissolved, the solution formed usually tends to keep up the strength of the electrolyte.

Among the most widely used depolarizers are the oxids of manganese, of copper, and of lead, and the chlorids of some of the metals. The several sulfates of mercury, on account of the large quantities of oxygen which they contain, are also used for this purpose.

52. Leclanché Cell.—The **Leclanché cell** is the best known and the most widely used cell of this type. It is used more by physicians than all other cells taken collectively. Its positive element is zinc, usually in the form of a rod; the electrolyte is a saturated solution of ammonium chlorid (sal ammoniac), and the negative element is carbon, surrounded by manganic oxid (peroxid of manganese), which is the depolarizer. The oxid is in the form of a coarse powder, and is usually contained in a porous cup, which allows free access of the electrolyte to the depolarizer and the negative element. Fragments of crushed coke (or carbon in other forms) are often mixed with the manganic oxid to decrease the resistance of the contents of the cup.

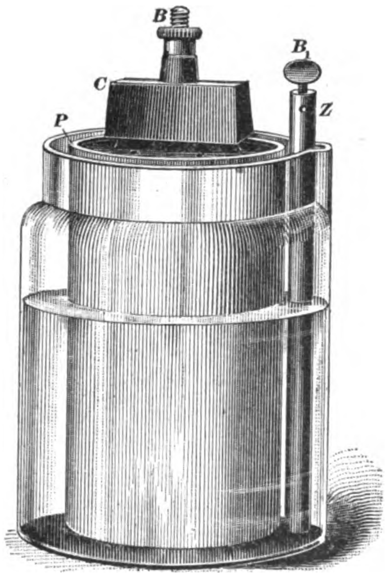


Fig. 10.

Fig. 10 shows the usual form of this type of cell. The porous cup *P* contains the manganic oxid and the carbon element, which projects from the top of the cup, a binding-post *B* being attached as shown. The glass jar is circular with a contracted top, in which a slight recess is formed for the zinc *Z*. The top of the zinc is provided with a binding-screw B_1, which serves as the negative terminal of the cell, *B* being the positive terminal. The top of the jar is coated with paraffin to prevent the crystals of sal ammoniac from "creeping" over the top of the jar as the liquid evaporates.

53. The cell illustrated in Fig. 10 has the following dimensions:

Jar	$4\frac{1}{2}''$ diameter, $6''$ high
Zinc	$\frac{3}{8}''$ diameter, $6\frac{1}{2}''$ high
Porous cup	$3''$ diameter, $5\frac{1}{2}''$ high
Carbon	about $6'' \times 1\frac{3}{4}'' \times \frac{5}{16}''$

The weight of the zinc rod is about 3 ounces, and two-thirds of it is usually below the level of the liquid. There are 16 ounces of peroxid in the porous cup, and it requires nearly

4 ounces of ammonium chlorid to make sufficient solution for this size of cell. For each ounce of zinc consumed in the cell, 2 ounces of manganic oxid and 2 ounces of ammonium chlorid must also be consumed; so, from the amount of these materials contained in the cell, it follows that there is enough peroxid in the porous cup to last while five or six zincs are being consumed, while the ammonium chlorid will not last longer than one zinc, as the zincs are usually replaced when eaten away to about $\frac{1}{8}$ or $\frac{1}{16}$ inch diameter. The consumption of zinc in the Leclanché cell is about 23 ampere-hours per ounce of zinc, and as about $1\frac{3}{4}$ to 2 ounces of each zinc rod may be consumed, the life of each zinc is then about 40 to 45 ampere-hours. The E. M. F. of this type of cell is about 1.48 volts, and its internal resistance about .4 ohms.

It is usual to seal the carbon and depolarizer into the porous cup by some compound such as sealing-wax, leaving small tubes or holes through which whatever gas not absorbed by the depolarizer may escape. This sealing necessitates the entire renewal of the porous cup with contents, when the depolarizer is exhausted; to obviate this expense, some makers use a carbon porous cup and place the zinc inside, at the center, the space between the zinc and carbon being filled with peroxid. To this class belong also the **Samson cell,** and the **Hayden cell.**

54. Gonda-Leclanché Cell.—Another widely used form of Leclanché cell is the **Gonda-Leclanché,** which uses no porous cup whatever; the manganic oxid is mixed with granulated carbon and some gummy substance, and compressed into cakes under great pressure. These cakes are attached to the sides of the carbon plate and act in the same manner as the depolarizer in the regular form. Other modifications have also been made to avoid evaporation of the liquid.

55. Lalande-Chaperon Cell.—To this class also belongs the **Lalande-Chaperon cell,** which uses iron or copper surrounded with a layer of cupric oxid, which acts as a depolarizer, as the negative element. The positive element is zinc and the electrolyte a solution of caustic potash.

56. Edison-Lalande Cell.—The **Edison-Lalande cell** is a modification of the Lalande-Chaperon. The cupric oxid is molded under pressure into plates of the requisite size, being first mixed with magnesium chlorid, which, when the molded plates are heated, serves to bind the mass together. These plates are held in copper frames enclosing the edges of the plates. The positive element in this cell is zinc, and the electrolyte a solution of potassium hydrate, or caustic potash. Two plates of zinc are used in most forms of this cell, one on each side of the cupric-oxid plate.

A cell of this type, having a capacity of 150 ampere-hours, is shown in Fig. 11. The cupric-oxid plate *C* is suspended in a copper frame *F*, *F* between the two zinc plates *Z*, *Z*, which are hung from each side of a lug on the porcelain cover of the jar. The sides of the copper frame of the oxid plate are carried up through the cover supporting the plate, and form terminals *B*, *B*, either of which may be used as the positive terminal of the cell. That part of the copper frame which projects above the plate *C* is protected from the action of the liquid by tubes of insulating material *T*, *T*. A binding-post B_1, on the bolt that supports the two zinc plates, serves as the negative terminal. A layer of heavy paraffin oil is used in this cell to prevent the action of the air on the solution.

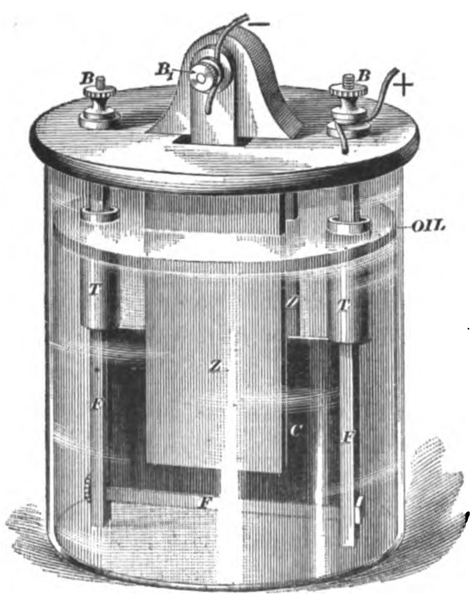


FIG. 11.

The 150-ampere-hour cell, shown in Fig. 11, is 5¼ in. × 8¼ in. outside dimensions, and will give a current of 3 amperes at a potential of about .7 volt for 50 hours, which is equivalent to about 100 watt-hours, with one "charge" of zinc, caustic potash, and oxid. The internal resistance of the above cell is about .07 ohm; the weight of the oxid plate is about ¼ pound. They are very constant and are able to furnish a large current; the local action is small.

DRY CELLS.

57. Construction and Use.—The name **dry cells** is usually applied to those having a solid depolarizer, in which the electrolyte is carried in the pores of some absorbent material, or combined with some gelatinous substance so that the cell may be placed in any position without spilling the liquid. These cells are generally made in small sizes, with zinc and carbon elements, the zinc, usually forming the outside of the cell, being made into a sort of cylindrical can, in the center of which is the carbon, surrounded by its depolarizing compound. The space between them is filled with some absorbent material, such as "mineral wool," asbestos, sawdust, blotting-paper, etc., and the whole is then soaked in the exciting liquid. In some the exciting liquid is mixed with a hot solution of some gelatinous body, such as isinglass or "Irish moss," which mixture is poured into the cell, and on cooling it forms a soft jelly. The first method of preparation is that most used.

It is evident that only a comparatively small amount of liquid can come in contact with the zinc at one time, hence the current-strength is not as great as that of an ordinary cell; they are therefore more adapted for smaller currents and for intermittent work. It is quite necessary, however, that they have a depolarizer, as otherwise they must be made open to allow the hydrogen to pass off, and this would allow the small amount of water they contain to evaporate. To prevent evaporation, the cells are sealed with some resinous compound.

The materials used in dry batteries are usually kept secret by the manufacturers; they all, however, answer to the above description as to construction, and the best types employ the same materials as the Leclanché battery; that is, a zinc element, an ammonium-chlorid electrolyte, manganic oxid or binoxid of manganese as a depolarizer, and a carbon element.

Some of these cells act very satisfactorily and are quite suitable for medical work, by reason of their portability and the small amount of attention and care required. If properly cared for, that is, if not used too much beyond their capacity, they will last from 1½ to 2 years, when they must be replaced by new cells. The smaller sizes weigh as little as 8 ounces, and measure 1½ in. × 1½ in. × 3¾ in.; their E. M. F. is about 1.5 volts and their internal resistance .65 ohm. A larger size has a resistance of only .25 ohm, and two of these used in parallel are sufficient to heat a short platinum wire for cautery-work to a white heat, and may also be used for operating induction-coils.

58. Hydra Semidry Battery.—The cells of which the **Hydra semidry battery** is made up have the advantages of the dry cell without its disadvantages. They are able to furnish a heavy current because the zinc is divided into two separate parts placed some distance apart in the electrolyte. These zinc elements are of a large surface area and will therefore give the depolarizer a larger field for its action at the same time, as it will decrease the internal resistance of the cell. Though the depolarizer is partly in a liquid form, the cell is so made that it is not possible to spill any of the liquid and the cell may either stand up or be laid on its side. This mobility of the electrolyte insures a more effective depolarization and makes it also possible for the fluid, by means of a special arrangement, to retreat when the cell is out of action. This will prevent any local action when the cell is not in use. They can be procured singly or in units of 4 cells, and may be renewed when exhausted.

THE APPLICATION OF PRIMARY BATTERIES.

59. Cost.—It was stated above that the cost of producing an E. M. F. by chemical means was far beyond that generated by motive power. But there may be cases where these conditions are reversed, when, in fact, it costs less to use primary batteries. Of course, these latter can never compete with motive power when it is a question of large units and constant supply, but when only a small current is needed at long intervals, and where in the meantime no material is consumed, the cost of the material is entirely offset by the small amount of attention required and the constancy of the source of supply.

The current from cells is much used for medical work; currents of a few milliamperes in strength, but of from 75 to 100 volts E. M. F., are applied for curative purposes; while currents of from 10 to 20 amperes in strength are used for heating cautery-loops in surgical operations, requiring an E. M. F. of from 4 to 8 volts. Miniature incandescent lamps are also employed to examine the various cavities of the body. Obviously, if the cells selected have a high E. M. F. (say, 2 volts), a less number will be required than if the cells are of a low E. M. F.

60. For furnishing the larger currents for cautery-work, large cells should be selected, those which are so arranged as to have a minimum internal resistance being best. As the use of porous cups in a cell increases the internal resistance largely, cells that employ them are not well suited for this work. Grenet cells are therefore very convenient for this purpose, as the resistance is low and the E. M. F. high and steady.

61. Mechanical Construction.—Attention must also be paid to the mechanical construction of the cells selected, as on this point often depends their life and suitability for the work they are called on to perform.

The binding-posts should be firmly and substantially fixed to the elements, and should be thoroughly protected from possible contact with the electrolyte, as the resulting action will so corrode the joint between the two as to destroy the contact, besides possibly eating away the connecting wires and breaking the circuit. Each binding-post should be provided with two openings for the reception of rheophores, or conducting wires; this will often save time and annoyance.

As much as possible of the material of the positive element should be below the level of the liquid, for when that is consumed the balance must be thrown away, and this may represent a considerable loss.

62. Consumption of Material.—In general, it must be remembered that the consumption of material in a primary cell (assuming no local action) is proportional to the output in ampere-hours; the *energy* output depends not only on the amount of material consumed but on the E. M. F. of the cell and its internal resistance, so that, other things being equal, the higher the E. M. F. of a cell and the lower its internal resistance, the greater its output for a given cost of material.

63. Internal Resistance.—It is evident that all the E. M. F. of a cell is not available to send a current through the external circuit, but that a part is expended in overcoming the internal resistance. If the external resistance is very great, as when sending a current through the human body, the E. M. F. expended in overcoming internal resistance is of little importance. On the other hand, if the external resistance is very small, as in cautery-work, the internal resistance practically determines the amount of current flowing. To obtain the maximum current-volume in an electric circuit, the external and internal resistance should be about the same.

SECONDARY BATTERIES, OR ACCUMULATORS.

64. Construction.—A **secondary battery, storage-battery,** or **accumulator,** as it is variously called, consists of an apparatus in which certain materials are so arranged that when a current is passed through the apparatus these materials are able to rearrange themselves in such a manner as to be able to act as a voltaic cell, and by chemical action produce electrical energy. Accumulators store *energy*, but not *electricity*, by converting the *kinetic energy* of the electric current into *chemical potential energy*, which may be realized again as kinetic energy.

Many forms of primary batteries may, when exhausted, be more or less regenerated by passing through them a current from some external source, in the opposite direction to the current they themselves produced. This current passed in the opposite direction restores the elements and the electrolyte of the cell to the condition in which they were before being used. It is customary, however, to consider as accumulators only those cells whose original construction is similar to an exhausted battery; that is, they cannot be used as sources of electricity until they have been *charged* by passing a current through them.

65. Positive and Negative.—Some confusion exists as to the use of the terms **positive** and **negative** in speaking of the plates of a secondary cell; for, in charging the cell, the current is in the reverse direction to that which flows when the cell is acting as a voltaic cell and discharging. It is customary, however, to speak of the plate at which the current enters the cell (while charging) as the positive plate. In fact, whether charging or discharging, this plate is at a higher potential than the other, which justifies the above use of the term, although, with respect to the chemical actions in the cell, the positive and negative plates are reversed in the two operations.

66. Classes of Accumulators.—Accumulators may be divided into two general classes: (1) *lead accumulators* and (2) *bimetallic accumulators.* The larger proportion of cells now in use is of the first class.

LEAD ACCUMULATORS.

67. Construction.—The original **lead accumulator,** as made by Planté, consists of two plates of lead, usually rolled together in a spiral and separated by strips of rubber or other suitable insulating material; these are placed in a 10-per-cent. solution of sulfuric acid. On sending a current from some external source through the cell, the water becomes decomposed, and the oxygen combines with the positive plate, forming lead oxid or peroxid, while the hydrogen collects at the negative plate. On disconnecting the source of the charging-current, and completing the external circuit of the cell, the water is again decomposed, the oxygen uniting with the hydrogen collected at the negative plate, and also with the lead plate itself; and the hydrogen uniting with the oxygen of the oxid of lead at the positive plate, thus producing a current in the opposite direction to that of the charging-current.

68. Oxidation.—Owing to the fact that the formation of the layer of oxid prevents further oxidation, the amount of chemical change due to the charging-current is small, so that the secondary current from the cell is of short duration. After this current has ceased, however, the surface of the positive plate is much increased, owing to the removal of the oxygen from the lead oxid, leaving the metallic lead in a spongy form. On again sending a current through the cell, a further oxidation of this (positive) plate takes place, and by continuing this process, reversing the current each time it is sent through the cell, both positive and negative plates become porous to a considerable depth; this very much increases the surface on which the oxidation can take place. This process might be carried on until the whole plate is reduced to spongy lead; in that case the plate would not hold together, so a sufficient amount of the original plate must be left for mechanical strength. After the plates are so *formed* they are ready to be used as an accumulator.

69. Faure Process.—This forming process, however, is too long and expensive for commercial success, though it may be considerably hastened by roughening the surface of the lead plates with nitric acid before commencing the process. It was soon superseded by the process, invented by Faure, of coating the surface of the plates with some substance that, by the first charging-current, is converted into lead peroxid on the positive plate and into spongy lead on the negative. This substance may be lead oxid (litharge), lead sulfate, minium Pb_2O_3, lead peroxid, or a mixture of these substances.

70. Grids.—These substances are applied in various ways. One method is to make a paste of the substance (in this case, usually minium), that for the negative plate being made with sulfuric acid—which changes the Pb_2O_3 into $PbSO_4$ (lead sulfate)—and water, while that for the positive plate is made with water only. These pastes were originally applied directly to the surface of the plain lead plate; but as they proved to be only slightly adhesive, the plates were prepared by scratching or otherwise roughening the surface, which process has been gradually extended until the lead plates are now cast into *grids*, or latticework plates, into the spaces of which the paste is put or forced by hydraulic pressure. Some manufacturers do not use a paste of the active material, but employ minium, litharge, or lead sulfate in the form of dry powder, forcing the powder into the grid under such enormous pressure that it is solidified.

After the grids have been filled with active material, they are set up in pairs, in suitable vessels, and surrounded with an electrolyte consisting of dilute sulfuric acid having a specific gravity of 1.17, which density corresponds to about 20 per cent. of acid in the liquid. A charging-current is then sent through the cell from some external source; the action of this current decomposes the water, the oxygen of which further oxidizes the lead oxid to peroxid at the positive plate. The hydrogen goes to the negative plate, where it reduces the lead sulfate to spongy lead by uniting with the SO_4, forming sulfuric acid. Thus, the active material becomes lead peroxid in the positive, and spongy lead in the negative, plate.

71. Gassing.—When the active material is thus all converted, continuing the charging-current produces no further effect, except to continue to decompose the water; the resulting gases then pass off through the water, giving it a milky appearance. This phenomenon is known as **gassing,** and it is an indication that the cells are fully charged. Continuing the charging-current beyond this point—that is, overcharging the cells—does no harm to the plates, but the energy represented by the current is wasted.

72. On discontinuing the charging-current at the gassing point, and completing the external circuit of the cell, a current will flow in the opposite direction to that of the charging-current, the resulting chemical action being to reduce the lead peroxid to lead oxid at the positive, and the spongy lead to lead sulfate at the negative, plate; a secondary action is the formation of a part of the lead oxid at the positive plate into lead sulfate. The sulfates thus formed are not all of the same proportions; one exists as red, another as yellow, and a third as white, crystals. Of these the white sulfate is best known, as it is formed when the cell is considerably discharged, and is extremely troublesome. This discharge may be continued until all chemical action ceases, and the E. M. F. consequently falls to zero; but this is not advisable, since, if the discharge is carried beyond a certain point, the red or yellow sulfates, probably by combination with the litharge PbO, form the white insoluble sulfate, which has a higher proportion of lead than the others; and this, being a non-conductor, naturally increases the internal resistance of the cell, and, when it is removed, usually carries some of the active material with it, as it is very adhesive.

73. Sulfating.—When the cells have been properly charged, the positive plate is of a brown or deep-red color, while the negative is a slaty gray. The presence of the insoluble sulfate is made apparent by the formation of a white coating or glaze over the plates, which are then said to be **sulfated.** If the cells are discharged and left to stand with the electrolyte in place, sulfating takes place rapidly.

As sulfuric acid is formed while charging, the density of the electrolyte will vary with the state of charge of the cell. When fully charged, the specific gravity will have changed from 1.17 to 1.22, but during discharge it will again return to its previous density.

The E. M. F. of this type of cell is approximately 2 volts, which gradually falls to 1.9 volts when nearly discharged. Beyond this point, further discharging causes the E. M. F. to fall more rapidly, the decrease after 1.8 being very rapid.

74. Buckling.—Notwithstanding the fact that accumulators are usually based on their capacity, when discharged to an E. M. F. of 1.8 volts, a long series of tests shows that they should not be continually discharged below 1.9 volts, as below this point sulfating is very liable to occur, and, the nature of the chemical action being changed, it leads also to the distortion of the positive plate, known as **buckling.** The buckling is liable to cause the plates to touch and thus to short-circuit the cell.

75. The cause of buckling seems to be the formation of a sulfate in the plugs of active material that fill the spaces of the grids, thus causing the plugs to expand; lead having very little elasticity, the grid is forced out of shape. As usually constructed, the edges of the grid are heavier than the intermediate portion, so that the effect of the distortion is to bulge the plate in the center. If the plates are not discharged too far and too rapidly, the expansion of the active material is gradual, causing the grid to stretch evenly; this makes the plates "grow," or increase in area, sometimes as much as 10 per cent.

76. The amount of material altered by chemical action in a completely charged cell determines the *quantity* of electricity which it may furnish; while the surface of the active material exposed to the chemical action determines the *rate* at which the material is altered, and, therefore, the *strength* of the current in amperes. Cells of this type are rated at a certain number of *ampere-hours* capacity, depending both on the weight and on the surface area of the active material in the cell. A certain economical *discharge rate* is also recommended, depending on the surface of the plates exposed to the electrolyte. The *voltage* of an accumulator depends solely on its chemical characteristics.

77. Ampere-Hours.—**Ampere-hours** is the product of the current-strength in amperes and the number of hours during which the current will flow before the capacity of the cell is exhausted. For instance, 100 ampere-hours means that a current of 100 amperes will flow for 1 hour, or 4 amperes for 25 hours, or any other combination the product of which is 100.

But it must not be supposed that with a given number of ampere-hours it is immaterial at what rate the battery is discharged. On the contrary, there is for each size a certain rate beyond which it is not advisable to go, and, if this discharge rate is continually exceeded, the chemical action goes on too rapidly, the white sulfate is formed in the active material of the positive plate, finally causing disintegration of the active material and buckling of the plates, even if the discharge is not carried beyond the point (1.9 volts E. M. F.) mentioned above. With the ordinary construction, the normal discharge *rate* is about .033 ampere per square inch of the positive plate, and the discharge *capacity* about 4.5 ampere-hours per pound of plate (both positive and negative plate included).

78. Output.—It is evident that the interior portions of the active material are affected much more slowly than the surface, as the acid penetrates the active material only at a comparatively slow rate. Reducing the rate of discharge therefore gives the active material more time to be uniformly and thoroughly reduced, thus giving a greater output. This is also the reason why the E. M. F. rises to its original value, if the discharge is interrupted at any point before a complete discharge has taken place.

If a cell is discharged at a rate beyond that most suitable for it, the output in ampere-hours will be reduced. Conversely, if the rate had been lower, the output would have been increased.

For example, assume the limiting E. M. F. to be 1.9 volts. In a certain cell, with a discharge-current of 30 amperes, the E. M. F. reaches its limit in 10 hours, giving an output of 300 ampere-hours. If the discharge-current were 40 amperes, the limiting E. M. F. would be reached in about 6½ hours, giving an output of only 260 ampere-hours; while, if it were 20 amperes, the limiting E. M. F. would not be reached for about 17½ hours, giving an output of 350 ampere-hours.

79. Efficiency.—The **efficiency** of the accumulator (or of any means of storing or transforming energy) is the *output* divided by the *input*. This quotient is always less than 1, as the accumulator is not a perfect storer of energy.

The *input* and *output* of an accumulator may be expressed either in ampere-hours (the quantity of electricity) or in watts (the *rate of doing work* of the current). If the cells be discharged at a normal rate, the *ampere-hour efficiency* will be ordinarily from .87 to .93, or 87 to 93 per cent. The *watt efficiency* at normal rate of discharge is lower, being from 65 to 80 per cent., depending on the construction of the cell. In a larger cell it may be as high as 84 per cent.

80. Loss Due to Internal Resistance.—The loss due to the internal resistance in well-designed cells usually amounts to about 8 per cent. at normal rate of charge and discharge. In a good modern cell, exposing 1,100 square inches of positive-plate surface, the internal resistance is about .005, when charged. Cells of greater capacity than the above (which is listed as 350 ampere-hours) would have a proportionately lower resistance.

81. Care of Cells.—If an accumulator of this class is not discharged at an excessive rate, nor to more than 1.9 volts E. M. F., the positive plates should last for about 1,200 or more discharges; while, if discharged each time to below 1.8 volts, or at excessive rates, the life of the positive plate will not ordinarily be more than 400 or 500 discharges. The negative plates, with good care, will usually outlast four or five positive plates.

82. There are several other kinds of treatment that will damage the cells. Among these is the habit of connecting the poles through a small resistance, to see if the cells are in good order. A current of great magnitude will flow for a moment and it will be likely to loosen the paste and cause sulfating in the cell. Either a voltmeter or a small incandescent lamp should be used for this purpose. When the cells are used for heating a large cautery, they should not be turned on suddenly, but gradually, by means of a variable resistance.

83. Construction of Cells.—The usual construction of the cells is as follows: The plates and electrolyte are contained in a vessel of an approximately cubical form; this vessel is of glass, if the cells are not intended to be portable, as the glass allows the condition of the plates to be ascertained while the cell is in operation. If the cells are intended to be portable, the vessel is usually made of hard rubber, or of wood lined with hard rubber or lead. The plates are usually approximately square, and from $\frac{1}{4}$ to $\frac{1}{2}$ inch thick, according to size. To get a large surface area without using single large plates, and to allow of one size of plate being used for cells of various capacities, each cell contains a number of positive and negative plates, arranged alternately, side by side, a short distance apart. The number of negative plates is always one more than the number of positive plates, so that *each side* of each positive plate has presented to it the surface of a negative. All the positive plates are connected together by a connecting strip, usually at one corner of the plate, and all the negative plates are similarly connected. The arrangement of a typical accumulator-cell is represented in Fig. 12, where the plates marked *N* are negative and those marked *P* are positive. From a corner of each plate a lug projects; the lugs on the negative plates are joined to a connecting strip, as represented at *T*, and the lugs on the positive plates are similarly joined to a connecting strip *T'*. These connecting strips are extended beyond the limits of the cell, and serve to connect the various cells of the battery together, as shown at *C*, the connection being made by a brass bolt, which firmly clamps the connecting strips together.

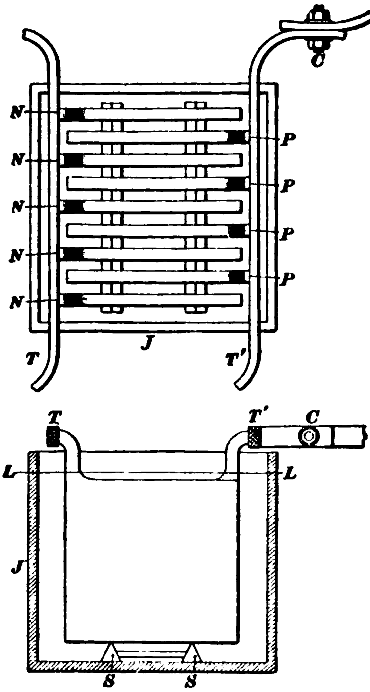


FIG. 12.

The plates are placed in the jar *J*, and they rest on a support made from two strips of wood (usually boiled in paraffin) of triangular section *S S*. These support the plates at such a height that any loosened particles of active material fall below the level of the bottom of the plates, thus preventing possible short-circuiting. When in position, the electrolyte is poured in until it reaches the line

L L, thus covering the plates. The plates are usually kept separate by blocks of insulating material.

84. Chlorid Accumulator.—A form of cell in which the plates, it is claimed, combine the cheapness of preparation of the pasted plate with the greater solidity and longer life of the Planté plate, is the **chlorid accumulator.** The plates of this type of cell are made as follows: A mixture of zinc chlorid and lead chlorid is melted and run into molds, which form it into cylindrical pellets, or pastils. These have a bevel-shaped edge. The pellets are placed in a second mold, being held in position by steel pins, and an alloy of lead and antimony is melted and forced in between the pellets, under heavy pressure. When this cools it forms a plate, binding all the pellets of zinc and lead chlorid together.

85. This plate cannot be used in this form in an accumulator; a number of these are first set up in a bath of dilute zinc chlorid with plates of zinc, to which the lead plates are connected. These plates then act as the elements of a primary battery, and the resulting chemical action dissolves the zinc chlorid contained in the pellets, and converts the lead chlorid into metallic lead, which assumes a crystalline form. The plate is now practically a continuous lead plate, solid and dense in some parts and porous in others. The plates in this condition are suitable for negative plates; those required for positive plates are then set up with plain plates in a bath of dilute sulfuric acid, and a forming current sent through them from the prepared to the plain plates. This current causes the porous parts of the plates to be formed into lead peroxid and into lead sulfate; the plate is now the equivalent of a pasted plate, and is an improvement through having its active material firmly bound in place in the composite grid.

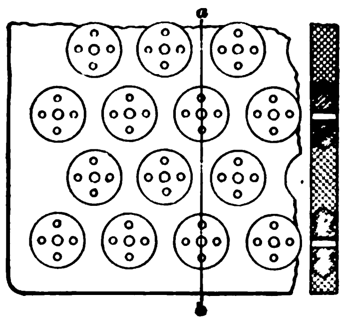


FIG. 13.

Fig. 13 shows a part of one of these plates; the section taken along the line *a b* shows the shape of the plugs. The holes in the plugs are caused by the pins by which they are supported in the mold. The requisite number of these prepared plates are then set up together to form a cell, positive and negative plates alternating and being connected to common conductors, as in other types of cells. (See Fig. 12.) The plates are each surrounded by a sheet of asbestos paper, and are separated from each other by a thin wooden strip, so thoroughly perforated with large holes that it really fills little of the space between the plates.

86. The E. M. F. of this form of accumulator is the same as that of the Faure (pasted) type or the Planté. It is claimed by the manufacturers that, because of the solidity of the construction, buckling and loosening of the active material are practically impossible, so that the cells may be discharged to a low E. M. F. or at high rates without serious injury. Its output per pound of element is greater than that usually assigned to lead accumulators, being about 5 ampere-hours per pound of plates (both positive and negative) at normal discharge rates.

BIMETALLIC ACCUMULATORS.

87. Classes.—In this class of cells the elements consist of two different metals, the electrolyte being a salt of one of the metals. There have been several combinations of materials proposed for cells of this type, but the only cells that have been actually used to any extent are the zinc-lead, copper-lead, and copper-zinc cells.

Few of these cells are suited for the use of the medical practitioner, partly because they require a daily discharge, being unable to retain their charge more than a few days, and also because the cells are constantly disintegrating, both when used and when not. The only exception to this is the Edison storage-battery, which is claimed to be superior to any of the bimetallic as well as to the lead accumulators.

88. Edison's Storage-Battery.—Among the advantages claimed for this battery are the following:

1. Absence of deterioration by work.
2. Large storage capacity per unit of mass.
3. Capacity of being rapidly charged and discharged.
4. Capacity of withstanding careless treatment.
5. Relative cheapness.

The negative pole is attached to an element consisting of a finely divided compound of iron with an equal volume of graphite flakes, and the positive to one consisting of superoxid of nickel; it may therefore be called a nickel-iron cell. The electrolyte is potash, preferably a 20-per-cent. solution of potassium hydroxid, the freezing temperature of which is 20° below zero, Fahrenheit.

The initial voltage of discharge is 1.5, while the mean voltage of full discharge is approximately 1.1 volts. The normal charging current rate is about 8.64 amperes per square foot. Charging and discharging rates are alike and may be $3\frac{1}{2}$ or only 1 hour without any apparent detriment.

The positive and negative plates are mechanically alike, and consist of a thin sheet of steel in which rectangular holes are stamped. Each hole or opening is filled with a pocket or shallow box containing the active material; the box is perforated with numerous small holes to admit the electrolyte, but conceals entirely the contained active material from view. The cell may be fully discharged to the practical zero point of E. M. F. without detriment.

USES OF ACCUMULATORS.

89. Advantages.—When, for medical purposes, a current of considerable strength is occasionally required, with long intervals between, accumulators constitute an ideal source of electric power. Primary cells might be directly applied in such cases, but on account of their high internal resistance either a considerable number of small cells or many large cells would be required to furnish the necessary current. If, however, primary cells, say of the gravity or other type, giving a constant E. M. F., are used to charge secondary cells, the charging can go on continuously day and night at a slow rate, and at any time the secondary cells may be drawn upon for a considerable current, far beyond the capacity of the primary cells themselves. This method is often adopted in surgeons' offices, where a considerable current is occasionally required for cautery-work or other purposes.

90. Charging-Current.—It has been found that in charging an accumulator only a small part (about 8 per cent.) of the E. M. F. required to force the current through the cell is expended in overcoming the resistance of the plates and the electrolyte; the remainder is expended in overcoming the E. M. F. of the chemical action of the cell. It follows, then, that if the *applied* E. M. F. be just equal to the E. M. F. of the cell, no current will flow, so that the E. M. F. of the cell itself may be considered as a counter E. M. F. opposing that of the charging-current. To apply Ohm's law $\left(C = \frac{E}{R}\right)$ to this case, E must be considered as representing the *algebraic sum* of the applied and the counter E. M. F., or $E =$ applied E. M. F. — counter E. M. F. This is another way of saying that the E. M. F. *required to drive the charging-current through the cell* is not only that required to overcome its ohmic resistance, but that to this must be added an E. M. F. equal and opposite to the E. M. F. of the cell itself, due to the chemical affinity of the substances of which it is composed.

In charging, then, if from any cause the E. M. F. of the charging-current be changed by a small amount, the charging-current will be altered in a much greater degree, depending on the ratio between the applied E. M. F. and the difference between the applied and the counter E. M. F. For example, consider a cell that has been discharged until its E. M. F. is 1.925 volts (on open circuit). The resistance of the cell is .005 ohm and its normal charging-current is 35 amperes. From Ohm's law: $E = C \times R$, we find the E. M. F. required to send this current through the given resistance. The necessary voltage is $E = 35 \times .005 = .175$ volt; but to this must be added the counter E. M. F. of the cell itself, viz., 1.925 volts. The applied E. M. F. must then be $1.925 + .175 = 2.10$ volts, in order to cause 35 amperes to flow. If the applied E. M. F. drops to 2 volts, it is evident that, the counter E. M. F. being the same, the available E. M. F. is $2 - 1.925 = .075$ volt, and the current that this E. M. F. would be able to drive through the cell is $C = \frac{E}{R} = \frac{.075}{.005} = 15$ amperes. Thus, a drop in the applied E. M. F. of $\frac{.1}{2.1}$, or about 5 per cent., causes the current to fall off more than 50 per cent. This shows the necessity of having the source of the charging-current so arranged that the E. M. F. may be closely adjusted, in order that the charging-current may be maintained at its proper value.

91. Charging of Accumulators.—Accumulators may be charged either by means of a primary battery, a small dynamo, or the commercial lighting current. The first method is the most expensive and would be used only in cases where there is no choice in the matter, as for instance, in isolated locations. Even then it would be preferable to use a small water or gas motor that could drive a direct-current dynamo, and in this manner supply the accumulator with the necessary current for charging. In cities where the incandescent-lamp current is available, then, it is undoubtedly the cheapest and most convenient method to use the latter for charging purposes.

The question may be asked, if the lighting current is at hand, why use storage-batteries? One reason is that the storage-battery is transportable and may be brought to places where they are the only means for providing an electric current. Another reason is that in cautery and Roentgen-ray work, currents are often required of a strength that is far beyond what the local lighting circuits are intended for, and the safety fuses would consequently burn out.

Detailed information about the charging of storage-batteries is found in *The Physics of Roentgen Rays* and *Physics of Light and Cautery*. The main thing is that the positive pole of the charging circuit is connected to the positive pole of the storage-battery. If there is any doubt on this point one of the various methods for testing the polarity of the conductors must be used.

92. Testing of Polarity.—One method is to dip the two conductors into a tumbler of water, holding them some distance apart. As twice as much hydrogen gas will be released at the negative conductor than oxygen at the positive conductor, it is easy to distinguish them, but great care must be used not to let the two conductors touch each other. In that case a very heavy current would pass through them, resulting in some damage to the circuit, as far as the burning out of fuses, etc., is concerned.

Various pole-testers are in the market that may be used for this purpose. They consist mostly of a glass tube into which two terminals are projecting, the tube being filled with some solution and sealed up. This solution may be one of iodid of potassium to which a small amount of starch has been added. Iodin is liberated at the positive pole and gives the starch a blue color. Instead of iodin, phenol-phthalein may be used; in that case, a red deposit is seen at the negative electrode.

93. Density of the Electrolyte.—A **hydrometer** should be used to ascertain the density of the electrolyte. The volume of the electrolyte will gradually diminish during the operation of the cell, due to evaporation and to the evolution of gas when the cell is charged; this loss should be made up by occasionally adding pure water or acid if the density, as indicated by the hydrometer, is too low.

94. Measurement of the E. M. F.—A **portable voltmeter** should also be provided which shall have a capacity such that the E. M. F. of a single cell may be accurately measured, so that, if the action of any cell seems to be irregular, its condition may be determined by measuring its E. M. F. and comparing it with that of the other cells.

SELECTION OF A BATTERY.

95. General Requirements.—It is not easy to select the proper cells for medical purposes. An ideal cell for both portable and stationary batteries would be one that is cheap, light in weight, and in little need of attention; but all these attributes are not found in one cell; and compromises must therefore be made. For a stationary battery, the size of the cell might not make much difference. When it comes to portability, the dry cells would seem to be the most suitable, but practice demonstrates that the Grenet battery renders the best service, when a heavy current is demanded. Lately the Hydra semi-dry battery has shown itself to be very efficient, delivering as much as 25 to 30 amperes.

96. Cautery and Lighting.—For cautery work and for lighting small incandescent lamps, then, undoubtedly a 2- and a 4-cell accumulator, respectively, will be the most serviceable. They should have a switch for arranging the cells in parallel or in series, and also an adjustable resistance. Should there be difficulties in recharging the battery, then a large-sized bichromate battery of, say, from 4 to 6 cells, may replace it. It is not advisable to have too many different kinds of batteries. It is better to make one battery serve as many purposes as possible; there will then be less expense for maintenance and less trouble in caring for them. The Daniell cell, the bichromate cell, or the Edison-Lalande may be used to recharge an accumulator, if no other means are at hand.

CARE OF BATTERIES.

97. Renewals.—In the care of batteries, there is little to add to what has been already said. A dry cell needs no attention so long as its E. M. F. remains constant; as soon as the latter begins to fall off very materially, the cell needs to be renewed. This is a distinct disadvantage, because one must mostly send to the manufacturers for a new cell. Edison-Lalande cells will work without further attention until exhausted, when new plates and solutions must be put in.

The Leclanché cells also require little care except an occasional addition of water to replace the amount lost by evaporation. Any tendency of the exciting liquid to creep over the edge of the cell must be prevented by coating the exterior of the upper part of the cell with paraffin wax. The red-acid cells last much longer when a small amount of mercuric bisulfate is added to the electrolyte.

98. Contact Surfaces.—When an acid enters into the composition of an electrolyte it is apt to cause trouble because of its tendency to oxidize the metallic surfaces connected with the cell. All oxids are poor conductors, hence the necessity of removing them with a piece of emery-cloth. As a contact surface cannot be too bright and free from all greasy substances, it is important to give the connections a great deal of attention. Should there be any suspicion about the contact surfaces of the connections, they must be rubbed with a piece of emery-cloth, and the various screw connections made tight to make certain that they will remain in good contact. It has already been said that the zincs must be amalgamated, and care must be taken that they remain so.

99. Care of Bichromate Cells.—It is less easy to take care of the bichromate cells and to know when the electrolyte needs renewing; but as a rule this ought to take place when its color is a dark green. Should the color of the electrolyte be orange, and the cell yet show some weakening in its action, then the addition of some sulfuric acid may improve it. If the bichromate cells are used daily, the electrolyte will need renewing in from 3 to 6 weeks. The elements should then be removed and suspended in a jar with cold water in which about a tablespoonful of salt has been dissolved; the water should not be permitted to wet the switchboard. Most of the impurities in the carbon will be dissolved when the water has assumed a greenish hue. After a thorough soaking, the elements are rinsed off in cold water and thoroughly dried with a rag. They are then replaced in the battery. The importance of lifting the zincs out of the electrolyte when not in use has already been dwelt upon.

100. Care of Electrodes.—When the battery has been used, the electrodes should never be thrown down in a careless manner, as either the battery as a whole or one of the cells may be short-circuited. Such a short circuit is deleterious to all batteries and to dry batteries in particular. The latter are in most cases permanently damaged by short-circuiting them, because the polarization that will take place is so excessive as to make it impossible for the cells to again recuperate. A few minutes of this accidental contact is enough to cause the damage; it is therefore advisable to form a habit of placing the electrodes in a proper position, where short-circuiting is impossible. Attention must also be given to the insulating covering of electrodes. After frequent use the insulating material will wear through, or it may be, at any time, accidently injured. In this case, the bare conductor may make contact with one of the metal connections and cause a short circuit. It is likewise possible that some instrument may in a hurry be laid down on the switchboard and make an unintentional contact between separate connections.

101. Poles.—After a battery has been disconnected for the purpose of cleaning or renewing, it is important to see that the connections are properly made and that the poles have not been reversed. Should there be any doubt on this point, it is well to make certain that the positive electrode has been connected to the positive binding-screw of the switchboard. For this purpose various pole-testers may be used; or a piece of moist litmus paper may be placed on a piece of glass and inserted under the ends of the two electrodes without letting the latter touch each other. Acid will be liberated at the positive pole and will redden the blue paper, while under the negative pole the red paper will turn blue.

ELECTRIC CIRCUITS.

CLASSIFICATION OF ELECTRIC CIRCUITS.

102. Voltaic Cell.—Before proceeding to the consideration of means, other than cells, employed in the production of an electromotive force, it is advisable to first consider the voltaic cell in connection with conductors of various resistances.

103. Circuits. — We have already seen, when studying Ohm's law, the general effect of an E. M. F. and of a resistance on the strength of an electric current; but there are certain other effects produced by the installation of a voltaic cell in a circuit, which call for very careful consideration, particularly as such combinations play a very important part in medical treatment.

1. *What Is a Circuit?*—First let us consider the meaning of the word *circuit*. It is evident that a battery, in and by itself, is of no utility as a therapeutic agent; it must, by means of a conductor, be brought in communication with some device or substance that is to be affected by the electric current. Let it, for instance, be supposed that a cautery is to be heated; then the positive binding-screws of the battery and cautery are connected together by one wire, and the negative binding-screws by another one. We have then what is termed a *circuit*—that is, a combination of an electric source with conductors and various receptive devices arranged in such a manner that the electric current is allowed to leave the source at one terminal, traverse the various conductors and devices, and return to the source at the other terminal. The whole path is the *circuit*, and it is said to be *closed* so long as the current is permitted to pass, and to be *open*, or broken, when the current is interrupted at some part, preventing a flow of electricity. In order that a current may flow, there must always be a closed circuit.

2. *Grounded, or Earth, Circuits.*—When the earth or ground forms part of a circuit it is called a *grounded circuit*, or an *earth*

circuit. Such connections are made when electrostatic machines are used, and are also utilized in telegraph lines.

3. *External and Internal Circuits.*—That part of a circuit which is external to the electric source is called the *external*

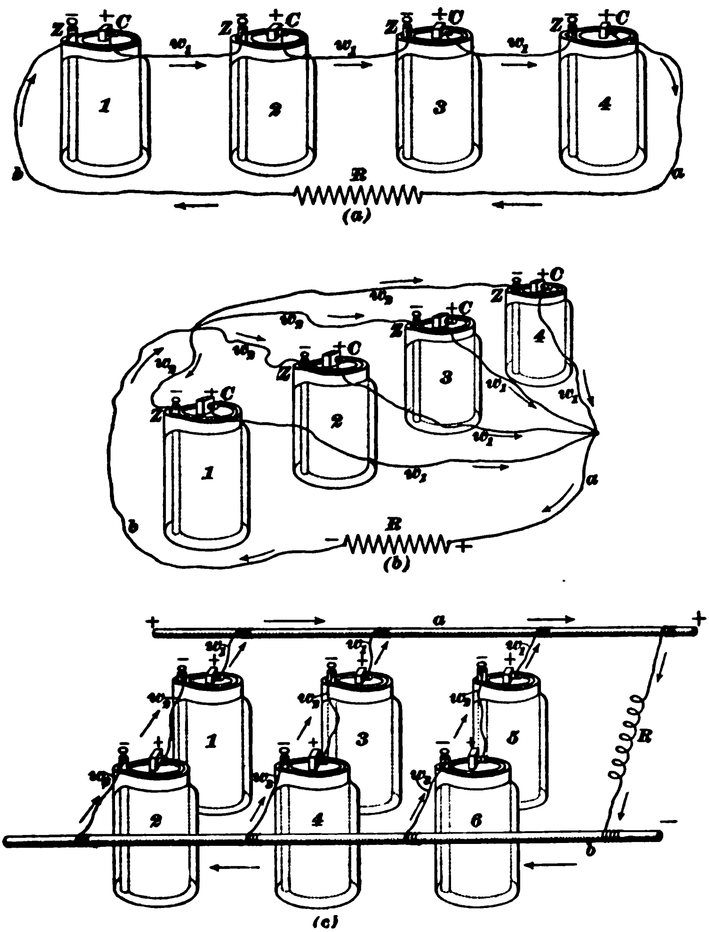


Fig. 14.

circuit, while the remaining part of the circuit, included within the electric source, is called the *internal circuit*. For instance, in the case of the simple voltaic cell, the internal circuit consists of the two metallic plates, or elements, and the liquid, or electrolyte; the external circuit would be some external body, as part or whole of the human organism, and the conductors by means of which it is connected to the cell.

4. *Divided Circuits.*—When a circuit divides into two or more branches, as in Figs. 19 and 20, where each branch transmits part of the current, it is called a *divided circuit;* the branches are said to be connected in *parallel.* Each branch taken separately is called a *shunt.* It is rarely the case that one primary cell or one accumulator cell alone is able to furnish either the E. M. F. or the current that is required in an electric circuit. Likewise is it exceptional that only one single receptive device is included in the circuit. In most cases a number of cells are required to give the required current-strength and these cells may then be arranged in various ways, depending on the conditions to be fulfilled.

5. *Series.*—When the cells are arranged in the manner indicated in Fig. 14 (a), they are said to be arranged in **series.** Four dry cells *1*, *2*, *3*, *4*, are here represented with their carbon binding-posts C and zinc binding-posts Z. Plus and minus signs indicate, respectively, the positive and negative binding-posts, while the arrows show the direction of the current. It is seen that the positive post of one cell is connected to the negative of the adjoining one by means of wires w_1, and that the two exterior posts are joined by means of the two conductors a and b to the resistance-coil R. The *whole* current passes successively through *every* cell.

6. *Parallel or Multiple.*—In the arrangement shown in Fig. 14 (b), the cells are so connected that each cell supplies only a *fraction* of the total current. Separate branch wires w_1 connect the positive binding-post of each cell with the common positive conductor a, and the other branch wires w_2 connect the negative binding-posts with the negative conductor b. Again R represents a resistance-coil inserted in the circuit. Arrangements in series and parallel are the two fundamental ones, and the following is simply a combination of the two.

7. *Parallel Series or Multiple Series.*—Several cells, as *1*, *2*, *3*, *4*, *5*, *6*, Fig. 14 (c), are made up in groups in which the cells

are connected with one another in series, and the various groups then connected in parallel. The wires w_1 connect each series-group with the common positive conductor a, wires w_2 connect the individual cells of each group, and wires w_3 connect each group with the negative conductor b. The two main conductors are joined by the resistance R.

As already said, these combinations do not refer to voltaic batteries solely, but also to electric lamps, dynamos, motors, in fact to any combination of electrical apparatus in which either an electromotive force is to be produced or utilized. Any combination of electric lamps, dynamos, motors, etc. is called a battery of lamps, dynamos, or whatever it may be. When speaking of a single voltaic cell it is incorrect to call this a battery.

The results that may be obtained by means of these various combinations will be more fully explained later.

104. It is evident that, in a combination in which a battery constitutes part of the circuit, the battery is not only acting as a source of E. M. F., but constitutes also a part of the total resistance of the circuit. We shall see later on that this internal resistance of the battery is under certain conditions very effective, and in many cases determines the most suitable arrangement of cells for the production of the proper current-strength.

105. When electromotive force was described and illustrated by means of Fig. 1, its general effects were considered only so far as they related to the starting of an electric current. We shall now proceed to consider more fully the variations an E. M. F. undergoes in passing from one part of a circuit to another.

LOSS OF ELECTROMOTIVE FORCE IN A CLOSED CIRCUIT.

106. "Watermotive" Force.—As soon as a voltaic cell begins to send a current through a circuit, there immediately arises in its path an obstacle in the form of a resistance, which has to be overcome; this can only be done by a certain expenditure of electromotive force. To make this more clear, we will again use as an analogy the flow of water in a pipe. In Fig. 15, T is a tank of water communicating with the pipe $E N$. If water is permitted to flow through this pipe, the quantity of water that passes at any point of the pipe will be the same, and the rate of flow, or the quantity that passes any point in 1 second, will also be the same so long as the level in the tank remains at the same height. Should the supply be insufficient and the level fall, then the flow would still be uniform in all parts of the pipe, but less water would flow through the pipe as a whole; that is, the rate of flow would be smaller. Although the *flow* is uniform, *the pressure per square inch* at the various parts of the pipe would not be the same. To convince ourselves of the truth of this statement, let us insert a series of tubes a, b, c, etc. in the upper side of the pipe $E N$. When the end N of the pipe is closed, we observe that the water will rise in all the tubes to the same level as that of the water in the tank; but as soon as water is permitted to flow through the outlet at N, this uniformity of level is disturbed

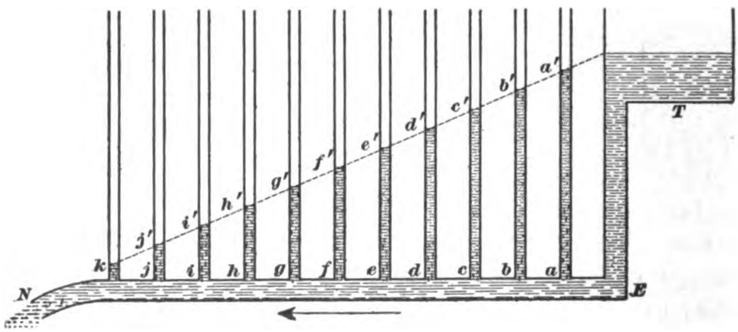


FIG. 15.

and we find the water in the tube nearest the outlet to be so low as to be hardly visible, while from N toward E the water-level in the other tubes gradually rises along a line k, j', i', etc., called the *hydraulic gradient*, until the water in the tube a is very nearly at the same level as the water in the tank. As these tubes are in reality pressure-gages, the water in each tube will only rise to such a height that the weight of the water-column in the tube is sufficient to counterbalance the pressure at that part of the pipe.

The question now to be answered is, Why should not the water in the vertical tubes remain at the same level as that of the water in the tank when the outlet at *N* is open? The answer is, Because the water in motion meets a certain frictional resistance along the inside of the pipe, which it can only overcome by losing some of its pressure. A similar case would be that of a sled gliding over an icy surface; its frictional resistance is small until it meets a sandy spot, where the pull must be materially increased, because a large amount of power has to be devoted to overcoming the increased friction. The pressure and the pull that are used in both cases are transformed into heat.

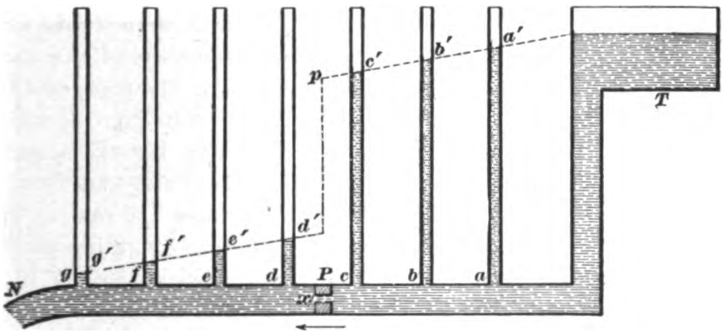


FIG. 16.

107. Loss in Pressure.—The total loss in pressure in the pipe *E N* is indicated by the difference in the level of the water in the tube *k* and that in the tank, and if we suppose the length of the pipe to be 12 feet and the level of the water in the tank 27.5 feet above that in *k*, then the pressure per square inch at *E* will be 12 pounds. If we further assume the cross-sectional area of the upright tubes to be 1 square inch, then the weight in pounds of the column of water in each tube will correspond to the pressure per square inch at the base of the tube in the pipe. The tubes are supposed to be 1 foot apart, and the reduction of pressure in each section or in each tube will therefore be $\frac{1}{12}$ of the whole, or 1 pound. The level in each consecutive tube will be 27.5 inches below that of the preceding one. We can see that the water in flowing from *E* to *a* has lost 1 pound in pressure, and that at *a* it has only a pressure of 11 pounds. This pound lost was consumed in overcoming the friction in section *E a*. When we proceed to the tube *f*, we find that the pressure has decreased by 6 pounds, and that a pressure of only 6 pounds remains for forcing the water through the rest of the pipe. The excess of pressure at *a* over that at *b* corresponds to the difference of level at *a'* and *b'*, and this is the pressure that is needed to propel the water through that section. The force which causes the water to flow through the whole pipe is that due to the difference in level between the water in the tank and at *N*, and may be called the **watermotive force.**

The loss in pressure which takes place in the various sections *a b*, *b c*, etc. is uniform so long as the cross-sectional area of the pipe remains the same and the sections are of the same length, but when a resistance is interposed in the pipe, the fall of pressure will be more sudden. This is seen in Fig. 16, where a plug *P* is inserted in the pipe. As there is only a small aperture *x* in this plug, through which the water can flow, it necessarily limits the *whole* flow and reduces its rate. The general loss in pressure will also be less corresponding to the reduced rate of flow. We see that the pressure suffers little reduction in the tubes *a*, *b*, *c* until the plug is reached, when the pressure falls very suddenly along the line *p d'*, the fall being caused by the friction to which the water is exposed in passing through the plug. After leaving *P*, the pressure again falls gradually along a line parallel to *a' p*.

108. E. M. F. in an Electric Circuit.—We are now in a position to more easily comprehend the action of an E. M. F. in an electric circuit. In Fig. 17, *1*, *2*, *3*, *4*, *5*, *6* is a battery of dry cells connected in series, the positive pole being connected to the binding-post *A* of a carbon rod *A L* and the negative pole to the other binding-post *L*. The battery may, in this case, be regarded as a machine that raises the pressure, or potential, of electricity from zero (or that of the earth) to an amount that may be represented by the line *a a'*, or, in other words, the distance $a a'$ represents the available *electromotive force* of the battery. If the connection were broken between L and A so that no current could flow we may suppose that the electric pressure imparted to the carbon would be evenly distributed along the whole length. This pressure may be represented by the line CD, its height above the rod $A L$ indicating the amount of this pressure. It is seen that this pressure is the same along the whole length of the carbon rod.

Let it be assumed that the E. M. F. of the battery is 12 volts, and that the total resistance of the rod $A L$ is 11 ohms, while that of the battery is 1 ohm; in all, therefore, 12 ohms. Each

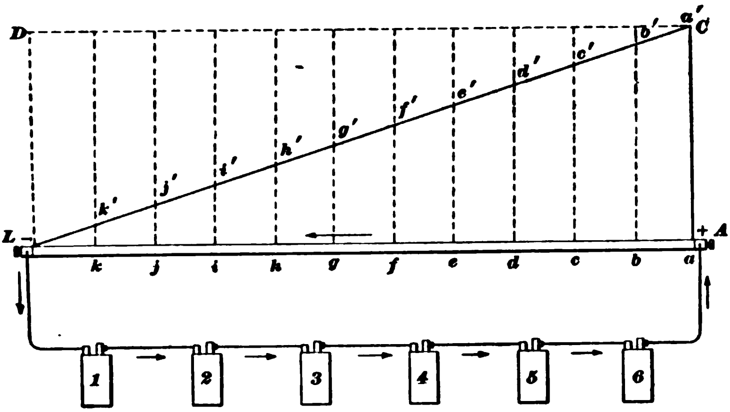


FIG. 17.

of the sections $a b$, $b c$, etc., of the rod will be of 1 ohm resistance, there being 11 sections. Knowing the total E. M. F. and the resistance, we can, by Ohm's law, find the current in amperes that will pass through the circuit. The formula $C = \frac{E}{R}$, in which $E = 12$ volts and $R = 12$ ohms, will give C the value of $\frac{12}{12} = 1$ ampere. The E. M. F. of the battery will therefore send a direct current of 1 ampere through the carbon rod $A L$.

109. Current-Strength.—As it was found that the same amount of water was flowing in any part of the pipe in Fig. 15, so we have the same amount of electricity flowing through any part of the conductor. No matter how much the pressure may vary from point to point in the circuit, the current-strength in amperes remains *constant.* The current-strength is always the same in all parts of the circuit. This must be borne in mind, as the mistake is often made of supposing the current-strength to vary in the several parts of a circuit in accordance with the E. M. F. The total E. M. F. of a circuit determines once and for all the resulting current, and the latter remains unaltered as long as the determining factors, E. M. F. and resistance, remain constant. The strength of the current will only change when either of these change, and then the flow will be altered at once in the *whole* circuit, not in parts of it. *When a change in current-strength occurs in a circuit, it does so uniformly, and not more in one part than in another.*

Let us now examine more closely into the alterations that the E. M. F. will undergo in the circuit illustrated in Fig. 17. We have already found that the resistance of 12 ohms will consume the entire E. M. F. of the battery; that is, the E. M. F. suffers a *loss*, or *drop*, of *electric potential* in the direction in which the current is flowing, and this difference of electric potential is caused by the flow of the electricity against the resistance of the conductor.

110. Drop of Potential.—The drop of potential between two points, say between a and b, is also found by means of Ohm's law; *the drop really represents the pressure or E. M. F. needed to send the current from a to b.* To find this E. M. F. we use the formula $E = C \times R$. The values of C and R were found to be 1 ampere and 1 ohm, respectively; E is therefore $1 \times 1 = 1$ volt; that is to say, there is a drop of 1 volt in each division $a\,b$, $b\,c$, $c\,d$, etc., and, as the resistance of the battery was 1 ohm, there is also a loss of 1 volt in the battery itself. If it is desired to find the loss of potential from a to d, the same formula is used, but one of the factors must now be changed; there are now three sections to consider, and therefore a resistance of 3 ohms. The formula will then read: $E = 1$ ampere $\times$ 3 ohms $=$ 3 volts; hence, the drop or loss in the part $a\,d$ is 3 volts.

The diagram also shows the loss of E. M. F. in any part of the circuit by drawing a vertical line from the point in question on line *A L* to line *C D*. Suppose, for instance, we wish to find the conditions at point *g*. The distance between the line *A L* and *C D* gives the total E. M. F. supplied to the conductor; of this E. M. F., the part above the line *C L* is lost, and the part below the line—that is, the line *g g'*—corresponds to the amount of E. M. F. that remains for sending the current through the rest of the circuit.

111. Battery E. M. F.—In the preceding example we did not consider that loss of pressure which the current suffers in

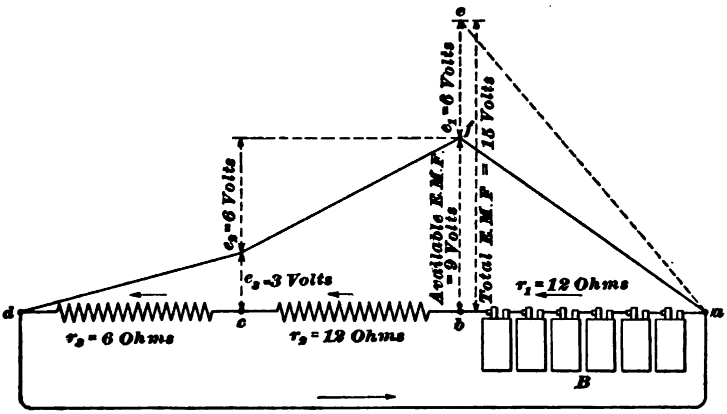


FIG. 18.

passing through the battery, but, as this is a point of some importance, it will now be considered more fully and illustrated by means of Fig. 18.

The calculation of the loss of E. M. F. between any two points is simple so long as the resistance of the circuit is uniform throughout its length. When the circuit is made up of parts with differing resistances, then more care is required to determine the real loss or drop. A circuit of this character is shown in Fig. 18. The entire circuit is divided into three parts: *a b* containing the battery of 15 volts E. M. F. and 12 ohms resistance, a resistance coil *b c* of 12 ohms resistance, and a conductor *c d* of 6 ohms resistance. These three resistances are designated by the letters r_1, r_2, and r_3, respectively; the circuit is completed by means of the return wire $d\,a$ with a negligible resistance.

The entire E. M. F. of the battery is represented by the line $b\,e$, and the drop of potential in the external circuit is supposed to take place along the line $f\,d$. Suppose it is desirable to find the loss of E. M. F. in each of the three divisions $a\,b$, $b\,c$, $c\,d$. Before this can be done, the current-strength of the circuit must be found. Here Ohm's law, $C = \frac{E}{R}$, is utilized; $E = 15$, and $R = r_1 + r_2 + r_3 = 12 + 12 + 6 = 30$ ohms; therefore, $C = \frac{15}{30} = .5$ ampere. When the battery B is arranged as in the present instance, the cells are in series, as shown in Fig. 14 (a). The nature of this combination will be made clear further on; for the present, it will be sufficient to know that the pressure of each cell is added to that of the preceding one until finally the pressure reaches the value of 15 volts, as indicated by the line $b\,e$. The line $a\,e$ would show the increasing pressure of the battery as we approach the terminal b, but, as the battery has a resistance of 12 ohms, evidently a portion of the pressure must be lost while the current is traversing the whole battery. The latter has therefore to be treated as the rest of the circuit, and the drop that takes place in the battery calculated before we can know what the E. M. F. in the external circuit will be.

The drop is found by the equation $E = C \times R$; since C is a constant all through the circuit, it is necessary to change R only, and in each case to substitute for R the values of r_1, r_2, or r_3, as the case may be, in order to find the various drops e_1, e_2, and e_3.

First, we have the battery itself, where $r_1 = 12$ ohms; therefore, $e_1 = C \times r_1 = .5 \times 12 = 6$ volts. The loss of voltage or drop that the current undergoes in passing through the battery is therefore 6 volts. Let us consider this point a moment, as it is necessary to be perfectly sure about this important part of the circuit. It was stated that the E. M. F. of the battery was 15 volts, and one would naturally suppose that this pressure would remain constant no matter what took place in the rest of the circuit. But we see now that this E. M. F. is

15 volts *only* when the battery is at rest, that is, when no current is flowing. As soon as the circuit is closed, the battery suffers like the rest of the circuit from the effects of resistance, and by reason of its resistance of 12 ohms, its E. M. F. of 15 volts is reduced to $15 - 6 = 9$ volts; that is, when the current enters the resistance-coil at point *c*, it has an E. M. F. of 9 volts only, and the line *a f* will therefore indicate the rise in pressure of the battery.

We now come to the resistance-coil *b c*; here, $e_2 = C \times r_2$, that is, $e_2 = .5 \times 12 = 6$ volts. The E. M. F. is now reduced by another drop of 6 volts, and 3 volts only remain. In the last division *c d* we have finally a resistance $r_3 = 6$ ohms, and the drop e_3 will be $C \times r_3 = .5 \times 6 = 3$ volts, a pressure sufficient to send the current to the battery through the return wire *d a*. The resistance and loss in the circuit is shown in the following table, giving the corresponding drop for the various resistances:

Resistance Ohms.	Loss Volts.	Current Amperes.
$r_1 = 12$	$e_1 = 6$	$C = .5$
$r_2 = 12$	$e_2 = 6$	$C = .5$
$r_3 = 6$	$e_3 = 3$	$C = .5$
Total, $r = 30$	$E = 15$	$C = .5$

DERIVED CURRENTS.

112. Conductivity.—So far we have considered the flow of an electric current in a single conductor. It is evident that there may be circuits in which the current flows between two points through two or more conductors, and that the current at these points will divide, one part flowing in one conductor and the other part in the other conductor. To know beforehand how many amperes will flow in each conductor or branch is of some importance, and the application of Ohm's law to a combination of this character will now be shown. It will be necessary beforehand to make an explanation of the word

conductivity. Various substances have been spoken of as good conductors, meaning that they offer little *resistance* to the passage of an electric current, or in other words, that they are of high *conductivity.* It is therefore evident that conductivity is the inverse of resistance, its reciprocal.

As the term *resistance* is that most frequently employed, the term *conductivity* is rather superfluous. In fact, though there is an established unit of conductivity, the *mho*, it is rarely used, the term conductivity being employed merely because it is convenient in a few calculations relating to divided circuits. For example, if the resistance of a circuit is 1 ohm, its conductivity is 1 mho; if the resistance is 2 ohms, the conductivity is represented by its reciprocal $\frac{1}{2}$ mho. If the resistance is increased to 4 ohms, the conductivity would be one-half as much as in the former case, or $\frac{1}{4}$ mho.

The conductivity of any conductor is, therefore, unity divided by the resistance of the conductor; and, conversely, the resistance of any conductor is unity divided by the conductivity of that conductor.

NOTE.—In treating derived currents, only that part of the circuit will be considered which is divided into branches and in which each branch transmits part of the total current; the rest of the circuit is assumed to be closed through some electric source, as, for instance, a voltaic battery.

113. Derived Circuit of Two Branches.—Fig. 19 represents a derived circuit of two branches.

Let r_1 and r_2 = resistances of the two branches;
c_1 and c_2 = currents through the two branches;
C = current in the main circuit.

Then, $$c_1 + c_2 = C.$$

When the current flows from a to b, if the resistances r_1 and r_2 are equal, the current will divide equally between the two branches. Thus, if a current of 2 amperes is flowing in the main circuit, 1 ampere will flow through each branch.

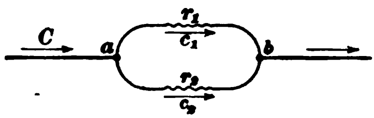


FIG. 19.

When the resistances are unequal, the current will divide inversely as the respective resistances of the two branches, or, since the conductivity is the reciprocal of the resistance, *the current will divide in proportion to their respective conductivities.*

In Fig. 19, the conductivities of the two branches are the reciprocals of the resistances r_1 and r_2; that is, $\frac{1}{r_1}$ and $\frac{1}{r_2}$, respectively. As the currents in the branches are proportional to their conductivities, we have

$$c_1 : c_2 = \frac{1}{r_1} : \frac{1}{r_2}, \text{ or } \frac{c_1}{c_2} = \frac{r_2}{r_1}.$$

Hence, $$c_1 = \frac{r_2}{r_1} \times c_2, \text{ and } c_2 = \frac{r_1}{r_2} \times c_1.$$

EXAMPLE.—Given, $C = 60$ amperes, $r_1 = 2$ ohms, $r_2 = 3$ ohms; find c_1 and c_2.

SOLUTION.—By formula $c_1 = \frac{r_2}{r_1} \times c_2$, we find $c_1 = \frac{3}{2} \times c_2$. But $c_1 + c_2 = C = 60$, or $c_1 = 60 - c_2$.

Substituting for c_1 its value $60 - c_2$, we get $60 - c_2 = \frac{3\,c_2}{2}$.

Transposing, $5\,c_2 = 120$, or $c_2 = 24$ amperes. Ans.

$c_1 = 60 - 24 = 36$ amperes. Ans.

114. Joint Resistance.—It is evident that two conductors in parallel will transmit an electric current more readily than one conductor alone; that is, their *joint* conductivity is *greater* than that of either taken separately. This being the case, their resistances must follow the inverse law; viz., the *joint* resistance of the two conductors must be *less* than that of either taken separately.

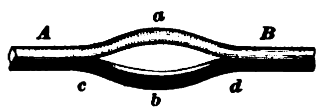


FIG. 20.

If the individual resistances of two conductors are equal, their joint resistance when connected in parallel is one-half of the individual resistance of either.

Suppose a conductor *A B*, Fig. 20, is split longitudinally into two halves *a* and *b*. If *A B* has a total resistance of 5 ohms between the points *c* and *d*, evidently the branches *a* and *b* must each have a resistance of 10 ohms, since they have only one-half of the cross-sectional area of *A B*. Thus, their joint resistance does *not* amount to $10 + 10 = 20$ ohms, but to $\frac{10}{2} = 5$ ohms, only.

When the individual resistances of two conductors in parallel are *unequal*, the determination of their joint resistance when connected in parallel involves some calculation.

In Fig. 19 the conductivities of the branches are $\frac{1}{r_1}$ and $\frac{1}{r_2}$, respectively.

Let $K =$ their joint conductivity;
$R =$ their joint resistance.

Then, $$K = \frac{1}{r_1} + \frac{1}{r_2} = \frac{r_1 + r_2}{r_1 r_2};$$

$$R = 1 \div \frac{r_1 + r_2}{r_1 r_2} = \frac{r_1 r_2}{r_1 + r_2}.$$

Rule.—*The joint resistance of two conductors in parallel is the quotient obtained by dividing the product of their individual resistances by the sum of their individual resistances.*

EXAMPLE.—In Fig. 19, given, $r_1 = 4$ ohms, $r_2 = 6$ ohms, find the joint resistance R of the branches from a to b.

SOLUTION.—Using the formula $R = \frac{r_1 r_2}{r_1 + r_2}$, we have

$$R = \frac{4 \times 6}{4 + 6} = \frac{24}{10} = 2.4 \text{ ohms. Ans.}$$

115. 1. *The joint resistance of three or more conductors in parallel is equal to the reciprocal of their joint conductivity.*

Fig. 21 represents a derived circuit of three branches. Let r_1, r_2, and $r_3 =$ the individual resistance of the three branches, respectively; therefore, $\frac{1}{r_1}$, $\frac{1}{r_2}$, and $\frac{1}{r_3}$ represent the individual conductivities of the three branches, respectively. Their joint conductivity is

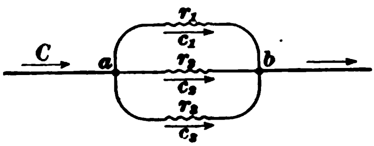


FIG. 21.

$$K = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3}.$$

Since the joint resistance is the reciprocal of the joint conductivity,

$$R = 1 \div \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3} = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2},$$

which is the joint resistance of the three branches in parallel from a to b.

EXAMPLE 1.—In Fig. 21, given, $r_1 = 5$ ohms, $r_2 = 10$ ohms, and $r_3 = 20$ ohms; find their joint resistance from a to b.

SOLUTION.—The joint resistance is

$$R = \frac{r_1 r_2 r_3}{r_1 r_2 + r_1 r_3 + r_2 r_3} = \frac{5 \times 10 \times 20}{5 \times 10 + 5 \times 20 + 10 \times 20}$$

$$= \frac{5 \times 10 \times 20}{50 + 100 + 200} = \frac{1,000}{350} = 2.857 \text{ ohms. Ans.}$$

2. To find the E. M. F. in a derived circuit when the current and resistance in each branch are known.

Rule.—*In any derived circuit, the difference of potential between where the branches divide and where they unite is equal to the product of the sum of the currents in the separate branches by their joint resistance in parallel.*

EXAMPLE 2.—If the currents in the three branches, Fig. 21, are 16, 8, and 4 amperes, respectively, and the joint resistance from a to b is 2.857 ohms, what is the difference of potential between a and b?

SOLUTION.—The sum of the currents in the branches is $16 + 8 + 4 = 28$, and $28 \times 2.857 = 80$ volts. Ans.

3. To find the individual currents in any branch of a derived circuit.

Rule.—*Determine the difference of potential between where the branches divide and where they unite, and divide the result by the resistance of the branch in question.*

EXAMPLE 3.—In Fig. 21, assume that the difference of potential between a and b is 80 volts, and that the individual resistances of the three branches are, respectively, 5, 10, and 20 ohms. What is the current in each branch?

SOLUTION.—The current in the first branch is $\frac{80}{5} = 16$ amperes; in the second, $\frac{80}{10} = 8$ amperes; and in the third, $\frac{80}{20} = 4$ amperes. Ans.

4. To find the individual resistance of any branch of a derived circuit.

Rule.—*Determine the difference of potential between where the branches divide and where they unite, and divide the result by the current in the branch in question.*

EXAMPLE 4.—In Fig. 21, assume the difference of potential between a and b to be 80 volts, and the currents in the individual branches to be 16, 8, and 4 amperes, respectively. What is the resistance of each branch?

SOLUTION.—The resistance of the first branch is $\frac{80}{16} = 5$ ohms; of the second, $\frac{80}{8} = 10$ ohms; and of the third, $\frac{80}{4} = 20$ ohms. Ans.

116. Effect of Tissue Resistance on Current-Strength.—This subject of branch conductors or shunts is of much importance to the physician, because the underlying principle is one that determines the amount of current that the various tissues or components of the human body are able to transmit when subjected to a certain E. M. F.

Suppose, for instance, that some tissue consisting of two layers *A E* and *C D*, Fig. 22, is to be treated by an electric current and that the latter enters at the electrode *a*, connected with battery *B*, and leaves at the other electrode *b*. In this instance it may be the intention to mainly treat the layer *C D* to a current of about 25 milliamperes, and when this current-strength is indicated by the meter *G*, the physician may be

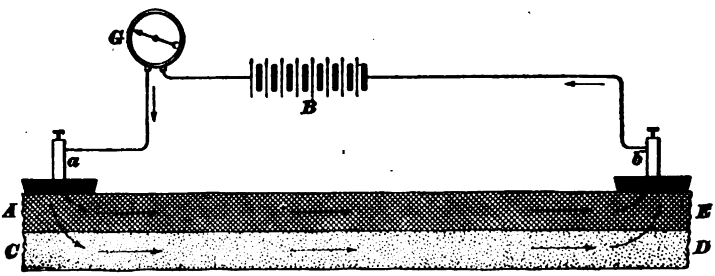


FIG. 22.

under the impression that the layer *C D*, in reality, is transmitting a current of this strength. If the layers *A E* and *C D* were both of the same conductivity, such might be the case, but when, for instance, *C D* has a much higher resistance than *A E*, then *C D* would receive only a small fraction of the total current.

Let the ammeter *G* indicate 25 milliamperes and the resistance of *A E* and *C D* be respectively 50 and 200 ohms. It is desirable to know how many milliamperes will flow through *C D*. From formulas given in Art. **113**, we find $c_1 = \frac{r_2}{r_1} \times c_2$. If c_2

stands for the current through CD and r_2 for its resistance of 200 ohms, while r_1 represents the resistance of AE, and c_1 the current-strength through same, we have $c_1 = \frac{200}{50} \times c_2$. But $c_1 + c_2 = C = 25$ milliamperes, the total current; therefore, $c_1 = 25 - c_2$.

Substituting for c_1 its value $25 - c_2$, we get

$$25 - c_2 = \tfrac{200}{50} c_2 = 4 c_2.$$

Transforming,

$$5 c_2 = 25, \text{ or } c_2 = 5 \text{ milliamperes. Ans.}$$

$$c_1 = 25 - 5 = 20 \text{ milliamperes. Ans.}$$

We see from this that the layer CD, instead of receiving 25 milliamperes, receives only 5. If it is desirable to provide

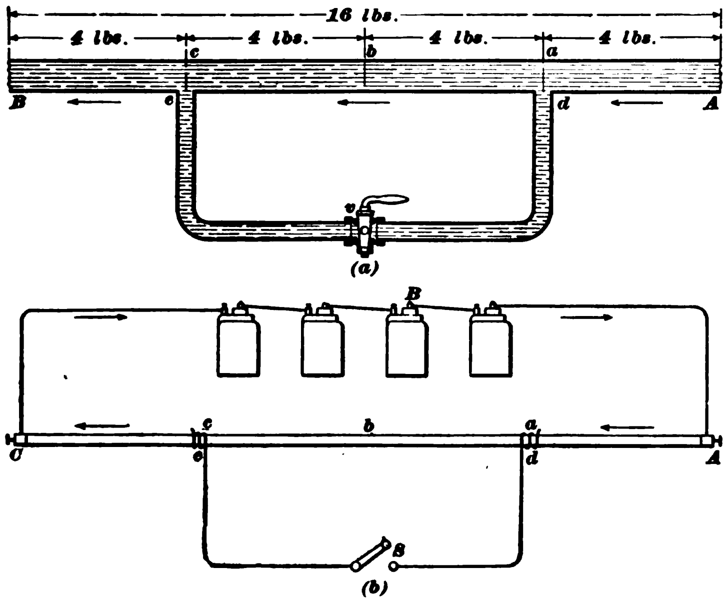


FIG. 23.

this layer with a current of 25 milliamperes, it will be necessary to increase the total current-strength to 125, when AE will receive 100 and CD 25 milliamperes.

117. Shunts.—This matter of branch conductors or shunts is of importance to the physician for still more reasons, and it will pay to study a few of the peculiarities of such conductors before proceeding any farther. To simplify the subject, we will first study the flow of water through a tube provided with a branch tube, as shown in Fig. 23 (*a*). Here *A B* is a portion of a long tube through which water is flowing in the direction of the arrow. The difference in pressure between the points *A B* is 16 pounds. If we imagine the tube divided in 4 equal parts *A a*, *a b*, etc., each of these divisions will suffer a loss in pressure of 4 pounds. That is, between *a* and *b* or *b* and *c* there will be a difference in pressure of 4 pounds, and between *a* and *c*, 8 pounds. If, now, a branch tube *d e* is connected to the main tube *A B*, it will be subject to a pressure of 8 pounds, and if the valve *v* is open, water will flow through it at a rate depending on its internal resistance. Such a branch is called a **shunt** because it shunts part of the main current.

It is evident that when water begins to flow through the shunt, conditions in the main tube are no longer the same. As part of the water now flows through *d e*, the resistance between *a* and *c* must have decreased because the combined resistance of *a c* and *d e* must be smaller than that of *a c* taken singly. Consequently, the difference in pressure between *a* and *c* will be no longer 8 pounds, but something less. For the same reason, the difference in pressure between *d* and *e* will remain 8 pounds only when the valve *v* is closed. After its opening this pressure will be reduced.

We may now apply these principles to the electric circuit shown in Fig. 23 (*b*). Here *A C* is a carbon rod through which a battery *B* of 4 cells sends a current. Assuming, then, that the battery has an E. M. F. of 8 volts and an internal resistance of 4 ohms, while the resistance of the rod *A C* is 4 ohms, the current $C = \frac{E}{R} = \frac{8}{4+4} = 1$ ampere. The rod *A C* constitutes $\frac{1}{2}$ of the total resistance, and for this reason $\frac{1}{2}$ the total E. M. F., or 4 volts, is spent while sending the current through it. If the rod also is divided into 4 parts as the tube in Fig. 22, there will be a difference in pressure between the points *A* and *a*, *a* and *b*, etc., each of 1 volt. Consequently, if points *a* and *c* are connected by means of the shunt *d e*, the latter will be subjected to a pressure of 2 volts as long as the switch S is open. On closing this switch a current will start to flow at a rate depending on the resistance of $d\,e$. Let this be 2 ohms, the same as that of $a\,c$. Evidently, the joint resistance of $a\,c$ and $d\,e$ will now be one-half that of either taken singly, or 1 ohm, and the difference in pressure between a and c should now fall to 1 volt, *if* the strength of the main current remained the same. But this is not the case, as *part* of the circuit has decreased in resistance; consequently, the *total* resistance must be smaller. The battery resistance is still 4 ohms, but that of the rod is now 3 ohms and the total resistance, therefore, $4 + 3 = 7$ ohms. $C = \frac{E}{R} = \frac{8}{7} = 1.14$ ampere. The loss of pressure or drop of potential in section $a\,c$ is $E = C \times R = 1.14 \times 1 = 1.14$ volts instead of the previous 2 volts.

These principles illustrated by means of Fig. 23 (a) and (b) are those made use of when using shunt rheostats for regulating the current-strength through the human body. Rheostats of this class in conjunction with others will be more fully explained in *Accessory Apparatus.*

ARRANGEMENT OF CELLS.

CELLS AS SOURCES OF ELECTRIC PRESSURE.

118. E. M. F. and Resistance.—As already explained, a voltaic cell or other apparatus from which an electric current is derived, must be considered as a source of electric pressure. To vary the strength of the current that the cell is able to furnish, will require either a variation in its pressure or its resistance. To vary the pressure of an individual cell is not possible, as the elements of which it consists determine once and for all this pressure. The only resources left are either to decrease the resistance of the cell itself or the external circuit, or to increase the pressure in the circuit by adding more cells, each of which will contribute its share to the total pressure. By the expression "decreasing the resistance of the cell itself" we do not mean that the resistance of the individual cell is decreased, but that several cells are combined into one in a manner so as to constitute one large cell, and thereby decrease the total internal resistance, as will be shown further on.

There is a simple hydraulic apparatus, a rotary pump, that has many qualities in common with a voltaic cell. To use this as a means for explaining the interaction between a voltaic cell or a combination of cells and an external circuit, will be of great assistance. The general features of this rotary pump are shown by means of Fig. 24 (a). It consists mainly of two gear-wheels A and B fastened on the shafts a and b, respectively. They are both supported and inclosed by the case C, into which lead the tubes c and d. When the gear B is set in rotation it will also drive the other gear A by means of the interlocking teeth, and, when the case is filled with water, a suction will be

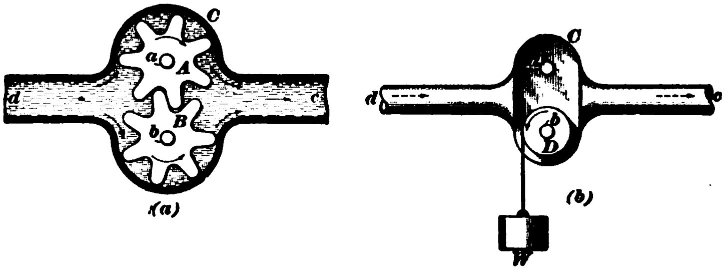


FIG. 24.

produced on the side next to the tube d. Water will be drawn in and carried around in the spaces between the teeth, in the direction of the arrows, and delivered on the side next to the tube c, through which the water is led away. As the case C fits the gears very closely all around, the water cannot escape, but must move with the gears. Fig. 24 (b) gives an external view of the pump, showing the ends of the shaft a and b. The latter has been provided with a pulley D around which a rope is wound that supports the weight W. It is seen that this weight will descend and set the pump in rotation and that water will flow through the tubes in the direction of the arrows. The main point to keep in mind here is that the weight of W is fixed and cannot be changed. It corresponds in this respect to the electromotive force of a voltaic cell. Like the E. M. F., the weight is ready at any time to set the pump in rotation and send a current through the pipes. How quickly the gears will revolve depends on the resistance that is offered to the flow of the current. This will be shown better by means of Fig. 25 (*a*), in which *c* and *d* constitute the ends of the pipe *P*, and where *V* is a valve by means of which the current may be wholly stopped or reduced to any desirable strength.

When the valve *V* is wide open the weight *W* will be able to set the water in motion and produce a current that will flow at a certain maximum rate. This rate will depend on the frictional resistance the current has to overcome either in passing through the case *C* or in flowing through the pipe. As the weight *W* is predetermined, this rate cannot be exceeded with one cell alone. Now, when the valve is partly closed the rate of flow will decrease, because part of the pressure is lost in overcoming the resistance of the valve. More pressure is now required at *c* to set the water in motion; in fact, it will be found that the greater the resistance interposed by the valve the greater will be the pressure at *c* and therefore also the difference

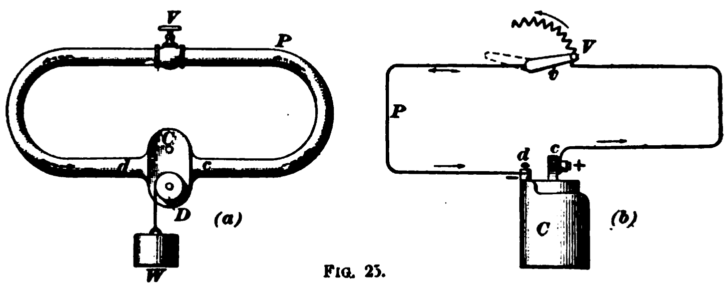


FIG. 25.

in pressure between *c* and *d*, until when the valve is entirely shut off the current will come to a standstill and there will be a maximum pressure at *c*. The motor will then also be at a standstill, but the weight W will be ready to start a current as soon as the valve is opened.

A counterpart of this hydraulic circuit is found in the voltaic cell *C* with conductor *P*, Fig. 25 (*b*). In place of the valve *V* we have a small lever *v* that may move over a coil of resistance wire and thereby include more or less resistance in the circuit.

By moving the lever into the position shown by means of dotted lines, the circuit would be broken entirely. The current passes through the binding-post *c* into the conductor *P* through the resistance *V* and lever *v* to the other binding-post *d* back to the cell. As with the pump, the current will flow at its maximum rate when the resistance of the circuit is at a minimum, and this minimum resistance is made up of the internal resistance of the cell and that of the conductor *P*. The E. M. F. being fixed, this rate of flow cannot be exceeded. By moving the lever *v* so as to include more and more resistance in the circuit, more pressure will be required to force the current through the resistance *V* and the difference in pressure between binding-posts *c* and *d* will continually increase. Finally, when the lever has been moved so as to break the circuit, the current will stop and the binding-posts *c* and *d* will now possess the maximum difference of potential.

It may not be clear why the pump or the cell should be able to deliver more pressure to the circuit when more resistance is

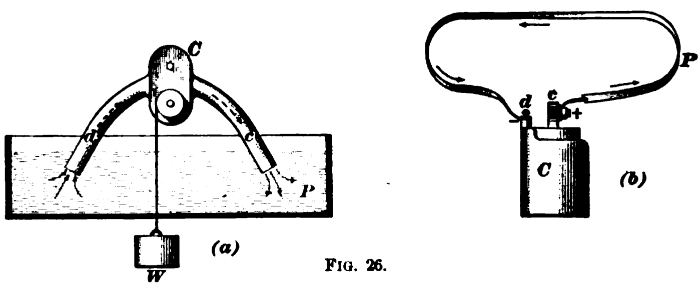


FIG. 26.

inserted in same, and the current consequently is decreasing in strength. The reason for this is that when the current is thus decreasing in strength it will lose less of its pressure in overcoming the resistance of the pump or cell itself, and more will therefore be at disposal in sending the current through the external circuit.

119. E. M. F. and Minimum External Resistance. After having considered an external circuit of maximum resistance we will go to the other extreme and consider one of no resistance, or one so small that it is difficult to measure it. A hydraulic circuit of this class is shown in Fig. 26 (*a*). The water flowing through the short pipes *c* and *d* might have been connected to another pipe of very large diameter that would constitute the external circuit, but they are here simply inserted in a tank *P* filled with water, the results being the same. The water delivered by *c* is deposited at one end of the tank and the water goes into *d* from the other end of the tank. When the tank is of large capacity the water would move very slowly toward the end where *d* is, because of the large cross-sectional area of the tank, and the loss in friction would be insignificant. The pump is now practically **short-circuited.** This is an electrical term used to signify that connection is established between two conductors of opposite polarity by means of a conductor of low resistance so that the whole current will pass through it instead of going through the regular path. It may also mean that two terminals of any source of electric pressure are connected by a conductor of so low resistance that a current of abnormal strength will flow through same. The pump will now work at its maximum capacity, beyond which it is not possible to go. It is clear that whatever resistance there is that limits the flow must be looked for in the pump itself. The whole energy delivered by the weight *W* to the pump is wasted in the form of friction between the water and the pump, and shows itself in he form of heat.

The same conditions prevail in the cell *C*, Fig. 26 (*b*). Here, also, is a short circuit established by connecting the two binding-posts *c* and *d* by means of a very heavy copper strip *P*, the resistance of which is negligible. These are the conditions under which the cell will deliver the greatest current, but it is all running to waste and simply results in heating the cell. Anyway, the cell would not be able to maintain this high rate of flow but for a short length of time, as polarization would quickly set in and reduce the current.

120. Cells in Series.—We have so far studied the possibilities of one cell alone and have seen that with a given resistance in the external and internal circuits the flow is limited to a certain rate. If the conditions are such that the current-strength has to be increased without reducing the *external* resistance, then the E. M. F. of the circuit has to be increased by increasing the number of cells. This is illustrated by means of a hydraulic circuit in Fig. 27 (*a*). Here the two pumps are connected in *series* and the water, after passing through pump C_1, is conducted through the tube *e* into pump C_2, from which it proceeds through *c* into the external circuit *P*. At *V* the tube is narrowed down to a small diameter, interposing a greater resistance to the current. Instead of the resistance *V* a pump like C_1 may be inserted that would act as a motor and raise a weight.

It is clear that when the water flows from C_1 with a certain pressure into C_2, it receives an additional pressure equal to that given by C_1, so that it now is in possession of twice the pressure it had when leaving C_1. For every additional pump added to

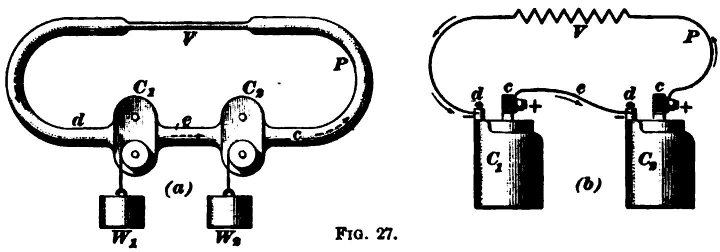


FIG. 27.

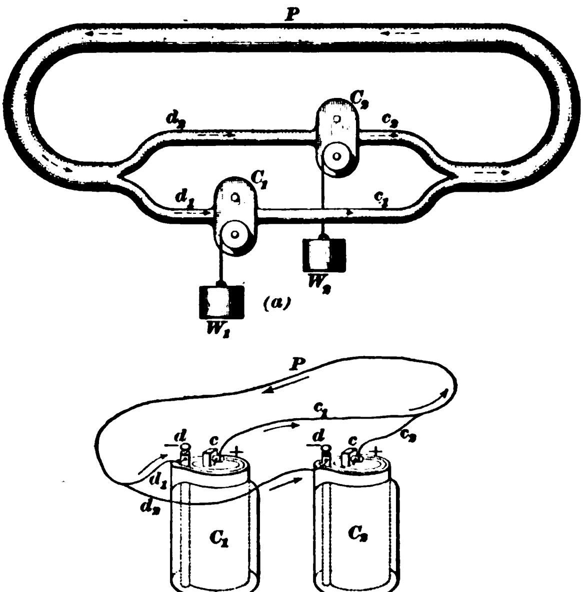
the series, the pressure would increase by an equal amount, assuming that all the weights are alike. It should here be kept in mind that *no* additional amount of water is added to the circuit; it is simply a question of an increase in pressure. We can imagine that if a motor were placed at *V* it should, if loss in friction be neglected, lift a weight corresponding to the sum of W_1 and W_2 at the same speed at which the latter are descending.

When this hydraulic circuit is transformed into an electric one it will appear as indicated in Fig. 27 (*b*). The cells are here in series, as previously explained, the carbon *c* of cell C_1 being connected to the zinc *d* of cell C_2. The current leaves the cell C_1 with a certain pressure and flows into cell C_2, where it receives the additional pressure the latter is able to supply. When the cells are in *series*, not only are the pressures of the cells united, but their *resistances* also. Since the current has to go through both resistances one after the other, the resistance is doubled. The resistance of the coil *V*, in addition to that of the cells, determines the current-strength. If this resistance of *V* is increased and it is desired to maintain the same current-strength, then the number of cells in series must be increased. As with the hydraulic circuit, no additional current of electricity is added to the circuit, each cell simply adds its pressure to that of the preceding one in the same manner as when a number of men pull a rope, each man contributing his share to the total pull.

121. Cells in Parallel.—When the external resistance of a circuit is *low* in comparison with that of the cells in series, as shown in Fig. 27 (*b*), then an addition of more cells in series will have little effect toward increasing the current-strength. We have, then, conditions somewhat similar to that shown by means of Fig. 26 (*a*) and (*b*). Each pump and cell sent a current through itself at such high rate that its whole energy was wasted in the interior of the pump or cell, and nothing was left that would be useful for the external circuit.

For instance, if the resistance in Fig. 27 (*a*) were made so low as to be practically a short circuit, then the pump C_2 would receive no assistance from pump C_1 and the result would be that no matter how many pumps would be added, the current-strength would remain that of one single pump. The same, of course, holds true with the electric circuit in Fig. 27 (*b*).

It is therefore clear that if we wish a heavy current in a circuit of low resistance we have to resort to other means. The proper arrangement for meeting these conditions is shown in Fig. 28 (*a*). In this instance, the two pumps C_1 and C_2 are arranged in *parallel*, each contributing an independent current to the main circuit through the branches c_1 and c_2, and again receiving their corresponding share through branches d_1 and d_2 from the main tube *P*. Arranged in this manner each individual pump does not add any more pressure to the circuit beyond that setting its own current in motion. We have, therefore, a number of separate streams, each of the same pressure uniting into one general stream. Therefore, adding any number of pumps will not increase the pressure, but simply the strength of the current. An electric circuit similarly arranged is shown in Fig. 28 (*b*). The two carbon or positive binding-posts *c*, *c* are connected by means of the branches c_1 and c_2 to the main conductor *P*. This means, in reality, that the two carbon elements are combined into one of double the surface area, and that each additional cell would increase the size of this carbon element. In the same manner, the



(b)

FIG 28.

zinc binding-posts are united by means of the branches d_1 d_2 to the conductor *P* with the result that all the zinc elements are combined into one. A large number of cells connected in parallel would therefore constitute *one* large cell, the E. M. F. of which would correspond to that of *one* cell, but with an internal resistance that would be reduced in proportion to the number of cells added on account of the increased surface area of the elements over which the electrolyte may act.

122. Cells in Parallel Series.—By adding more pumps or cells in the two branches, the pressure of each branch, and, therefore, of the whole circuit, will be correspondingly increased, and we would have a combination of cells in *parallel series.*

123. Summary.—Reiterating the conclusions arrived at, we may say, that in a circuit of *low* resistance an increase in current-strength may be attained by increasing the number of cells in *parallel.* In a circuit of *high* resistance the current-strength may be increased by increasing the number of cells in *series.* If the circuit is of medium resistance, relative to that of the cells, combinations may be made in *parallel series.* How the latter arrangements are made to best advantage will depend on the prevailing conditions.

124. Calculations.—In order to facilitate any calculations that the student may desire to make, either in finding the available current-strength from a battery of voltaic cells or one made up of storage-batteries, a few examples will here be given to show the application of the laws explained in the preceding pages.

Cells in Series.—It has been explained that when cells are placed in series, both the E. M. F.'s and the resistances of the single cells are added together. If we call the E. M. F. of the cell E, its internal resistance r, and the number of cells in series n, we have the total E. M. F. of the battery as $n \times E$; and total resistance of the battery as $n \times r$. The current-strength that it would be able to furnish on short circuit, that is, without any external resistance in circuit, would be $C = \frac{n \times E}{n \times r} = \frac{E}{r}$. This proves what was already mentioned, that when cells are placed in series on short circuit, or with a small external resistance, the current-strength of the whole series is not greater than that of a single cell. For instance, let E be 1.1 volts and $r = .6$ ohm; then, $C = \frac{E}{r} = \frac{1.1}{.6} = 1.8$ amperes. For 10 cells in series, or $n = 10$ we have $C = \frac{n\,E}{n\,r} = \frac{10 \times 1.1}{10 \times .6} = 1.8$ amperes, the same as before.

Cells in Parallel.—We have previously shown that when cells are arranged in parallel their total internal resistance is decreased in proportion to the number of cells added, following the law of joint resistances already given. The joint resistance of two cells in parallel would therefore be one-half that of a single cell, or for n cells the total resistance would be $\frac{r}{n}$, when r again represents the resistance of each cell. The total E. M. F. of the combination was seen to be that of one single cell.

For instance, if the two cells used in the preceding example be connected in parallel, their joint resistance would be $=\frac{r}{n}=\frac{.6}{2}=.3$. Therefore, the current-strength $C=\frac{E}{\frac{r}{n}}=\frac{1.1}{.3}=$ 3.7 amperes, which is twice the current-strength delivered when the cells were in series.

Cells Connected With an External Resistance.—In both of the last examples the cells were supposed to be short-circuited. These are conditions that are rarely met with in practice. As a rule, the cells are part of a circuit in which their resistance constitutes only a fraction of the total resistance, as shown in Fig. 18. It is such circuits as that we now wish to consider with the purpose of finding the combination of cells that will best fill the various requirements. The conditions are usually such that the external resistance is fixed, and the question is to find the least number of cells that will give the desired current-strength. To show more clearly how the external resistance affects the available E. M. F. and the current-strength, a series of diagrams have here been devised that will assist the student very materially in grasping the subject.

GRAPHICAL REPRESENTATIONS OF ELECTRIC CIRCUITS.

125. Electromotive Force.—It was already shown in Fig. 18 that, after the electric current leaves the battery and enters the external circuit, its E. M. F. is constantly *decreasing*, in some parts of the circuit more rapidly than in others, and these variations were shown by various gradients. Let the heavy line $a\,b$ in Fig. 29 (a) represent a conductor of a certain resistance and c_1, c_2 . . . c_5 a number of dry cells connected in

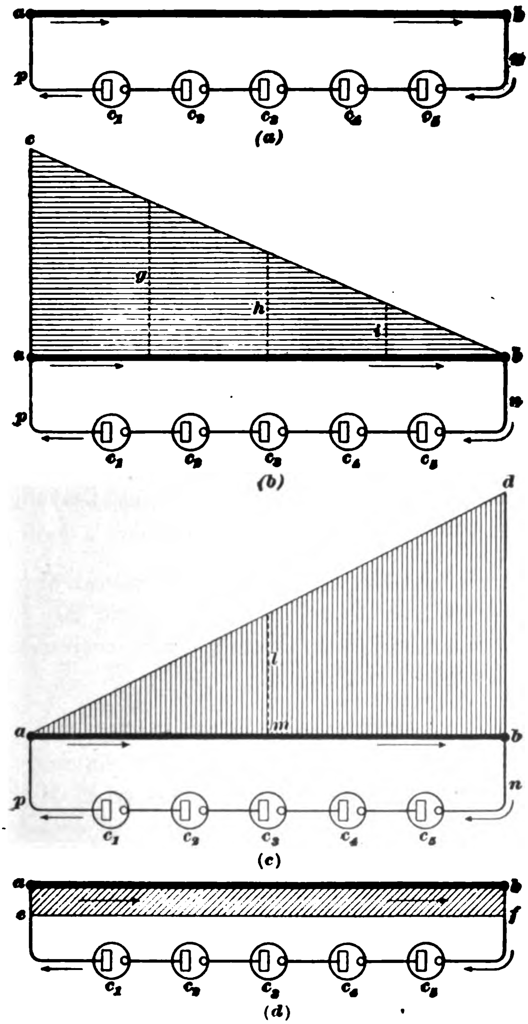


Fig. 29.

series and connected to $a\,b$ by means of the short conductors p, n. A current will then pass through this circuit in the direction of the arrows. The available E. M. F. of the battery will be at a maximum at *a* and decrease toward *b*. These conditions may be represented by means of Fig. 29 (*b*), in which the vertical line *a c* indicates the full pressure as delivered by the battery to the conductor *a b*. This conductor is supposed to be of uniform resistance and the E. M. F. is seen to fall gradually along the line *c b*. If the conductor be divided in four equal parts, and the lines *g*, *h*, *i* erected from the dividing points, each of these lines will represent the relative pressure at those points. For instance, if *a c* stands for 12 volts, *g*, *h*, and *i* would represent, respectively, 9, 6, and 3 volts.

126. Resistance.—The **resistance** of conductor *a b* is *increasing* from the point *a* toward *b*, as represented by the line *a d*, Fig. 29 (*c*). If the line *a b* be divided in the same manner as shown in Fig. 29 (*b*), and vertical lines erected, the latter will indicate the relative resistance at the various points. For instance, if *a b* be divided at *m* and the line *l* erected, the latter will be one-half the length of *b d* and indicate that the part *a m* is one-half of the total resistance of *a b*.

127. Current-Strength.—Finally, we can also represent the current-strength by drawing the line *e f*, Fig. 29 (*d*), parallel to *a b* at a distance below it that would correspond to the number of amperes flowing.

128. Combined Diagrams of E. M. F., Current-Strength, and Resistance.—Instead of having (*a*), (*b*), (*c*), and (*d*), Fig. 29, represent the relative E. M. F., resistance, and current-strength, it is possible to combine them. One is then able to see at a glance the relation between them. This has been done in Fig. 30. In the present instance, the resistance of the battery *B* has been left out of consideration, and only that of the conductor *a b* is considered. Let the available E. M. F. of the battery be 4 volts and the resistance of the conductor 4 ohms. If we now select some arbitrary length for 1 volt, and measure four of these along the line *a c*, we reach the point *c*; the line *a c*, therefore, is corresponding to an E. M. F. of 4 volts, and the line *c b* will show the gradual fall of the E. M. F. down to zero at *b*. In the same manner, the resistance of 4 ohms is laid off along the line *b d*, when the line *a d* represents the increase in resistance from zero at *a* to 4 ohms at *b*. Finally, if we let the

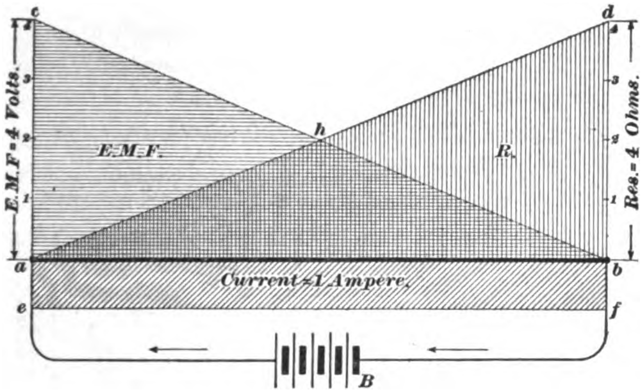


FIG. 30.

distance *a e* represent the current-strength of 1 ampere and through *e* draw a line parallel to *a b*, the line *e f* will indicate the

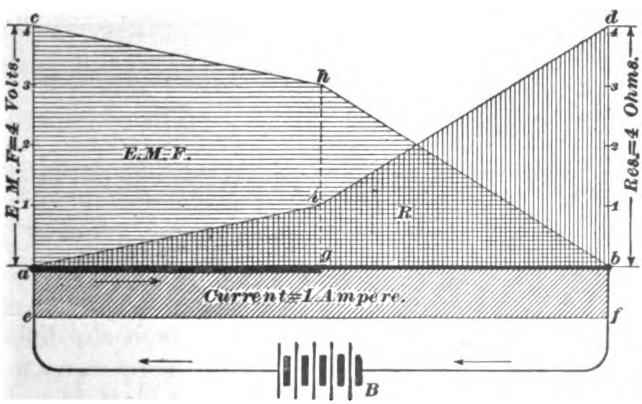


FIG. 31.

current-strength through the conductor, and it is of course uniform throughout its length.

129. Circuit With Non-Uniform Resistance.—We will now go a step further, and in the next diagram, Fig. 31, show the effect of a resistance that is not uniform. The resistance of the part *a g* of the conductor is 1 ohm, as shown by the line *g i*; the remainder of the conductor has a resistance of 3 ohms, that of the entire conductor being 4 ohms. The E. M. F. is, as before, 4 volts, which at point *h* has fallen to 3 volts, and between *h* and *b* it falls more rapidly to zero. The current of 1 ampere has again remained constant throughout the whole length of the conductor.

130. Resistance of Battery.—So far, the resistance of the battery has been left out of consideration, but as any

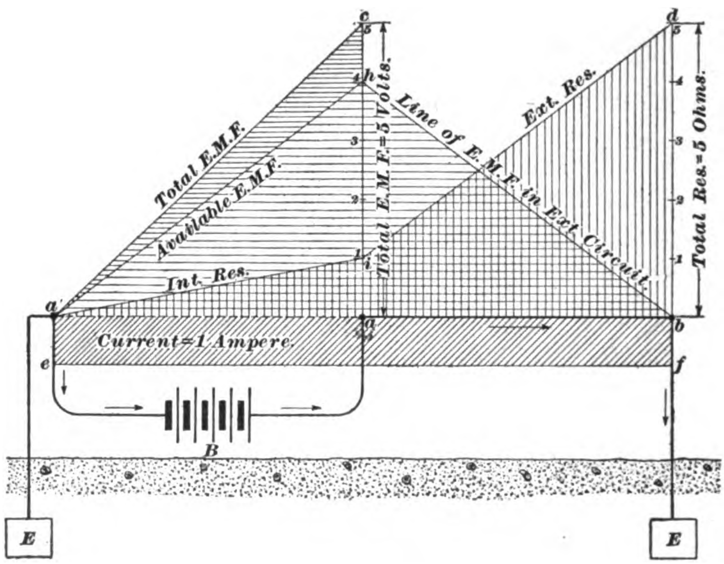


FIG. 32.

changes that take place in the external circuit also influence the battery in one way or another, it will be necessary to also include the latter in the diagrams.

In Fig. 32 is shown a battery of 5 cells in series, each cell being of 1 volt E. M. F. and .2 ohm internal resistance. The total E. M. F. is $5 \times 1 = 5$ volts, and the total internal resistance is $5 \times .2 = 1$ ohm. The external resistance is 4 ohms, which, together with the 1 ohm of the battery, makes the total resistance 5 ohms. For simplicity, the end *b* has in this instance been connected through the ground with the other end *a′*, as is the custom in telegraphy, it being assumed that this return circuit has a resistance so low that it can be left out of consideration. The current-strength C is then $\frac{5}{5} = 1$ ampere. The loss of E. M. F. in the battery will be $C \times r = 1 \times 1 = 1$ volt. These figures are represented in the diagram in the following manner: The line *a b* represents, as before, the external circuit, and *a a′* the internal circuit through the battery. The total E. M. F. is *a c*, and corresponds to 5 volts. We see that this E. M. F. is gradually rising from the point *a′*, each

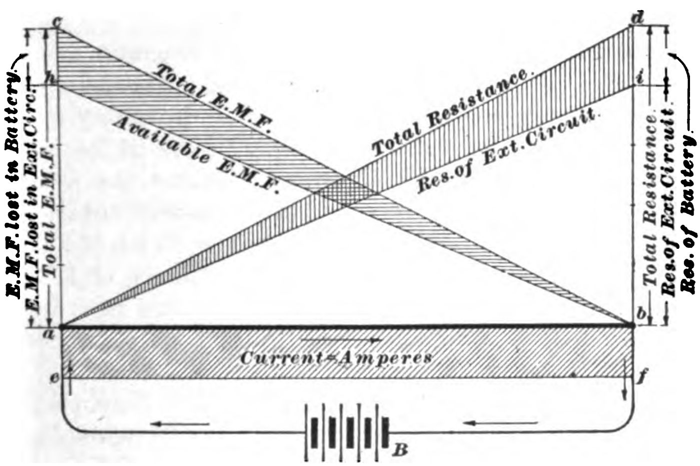


FIG. 33.

cell adding its E. M. F. until the fifth cell brings the pressure up to *c*. At the same time, the resistance of the battery has also been increasing, beginning at *a′*, the five cells, of .2 ohm resistance each, making a total of 1 ohm, as shown at *a i*. To this is added, at point *i*, the resistance of the external circuit, 4 ohms, making a total resistance of 5 ohms, as indicated by the line *b d*. Returning to the E. M. F. of the battery, it is observed that 1 volt has been lost in overcoming the resistance of the battery; this loss is represented by the line *c h*, and the triangle *a′ c h* shows the distribution of this loss. Hence, the available E. M. F. is only 4 volts, as indicated by the line *h a*. As soon as the current leaves the battery at *a*, the pressure begins to fall, and continues to decrease until the point *b* is reached, where the current again enters the battery. The current-strength is indicated by the line *a′ e* or *b f*, and is constant throughout the circuit. The circuit is supposed to be completed through the earth.

131. In order to still more condense the diagram shown in Fig. 32, it has been transformed to the form shown in Fig. 33. Here that part of the diagram which, in Fig. 32, was situated at the left of the line *c a* has, so to say, been folded over and laid on that part of the diagram which lies at the right of line *c a*. As the arrangement of cells will be treated by diagrams drawn in this form, a few additional explanations will not be out of place.

The line *a c* represents the total E. M. F. of the battery, 5 volts; the line *c h*, the loss of E. M. F. taking place in the battery itself. The triangle *a h b*, therefore, indicates the available E. M. F. The battery is connected to the external circuit *a b* at the terminals *a* and *b*, and we have, as before, the fall of E. M. F. in the external circuit along the line *h b*. The rise of E. M. F. in the battery can also be observed by proceeding from *b* along the line *b c*. The more heavily shaded triangle *b c h*, represents the E. M. F. lost in the battery. The battery resistance that causes this loss is shown by means of the more heavily shaded triangle *a d i*, *d i* being 1 ohm; the triangle *a b i* represents the resistance of the external circuit. The current-strength is, as before, indicated by the distance of the line *e f* from *a b*, being proportional to the length of the line *a e* or *b f*.

132. Fundamental Formula.—We have so far found means for calculating the current-strength when all the cells were arranged in series or in parallel, but have no convenient means for arriving at the current-strength when the cells are arranged in parallel series. There is a fundamental formula that will solve any question in this line and that will serve as well for cells in series as in parallel. In the following formulas,

C = total current-strength;
r = internal resistance of one cell;
r' = total battery resistance;
R = external resistance;
e = E. M. F. of one cell;
E = total E. M. F. of the battery;
s = number of cells in series;
p = number of cells in parallel;
n = total number of cells.

As already mentioned, the total E. M. F. of a battery depends on the number of cells in series; therefore, $E = s \times e$.

The total internal resistance depends on whether the cells are in series or parallel, or in a combination of both series and parallel.

If all the cells are placed in series, the internal resistance $r' = s \times r$; if placed in parallel, $r' = \frac{r}{p}$.

When the cells are partly in series and partly in parallel,

$$r' = \frac{s \times r}{p}.$$

From this we will find that the total current which the battery is capable of sending through the external resistance R is found, in *parallel series*, as follows:

$$C = \frac{E}{r' + R}.$$

Therefore, $$C = \frac{s\,e}{\frac{s \times r}{p} + R}. \qquad (a)$$

This formula can be used for any number of combinations of cells in *parallel series*, or for a single row of cells, either in *series* or *parallel*.

In using the formula for cells in *series*, it will appear in this form:

$$C = \frac{s\,e}{\frac{s\,r}{1} + R}.$$

Therefore, $C = \frac{se}{sr + R}$. (*b*)

For cells in *parallel*, the following formula will be evolved:

$$C = \frac{1 \times e}{\frac{1 \times r}{p} + R}.$$

Therefore, $C = \frac{e}{\frac{r}{p} + R}$. (*c*)

133. Effect of Combining Cells.—Let us, by means of a few examples, see the effect of combining the same number of cells (1) in *series*, (2) in *parallel*, and (3) in *parallel series.*

Suppose it is desired to send a current through an external resistance of 5 ohms by means of 12 Daniell cells, each of which has an internal resistance of .6 ohm and an E. M. F. of 1.1 volts.

Then, $e = 1.1$;
$r = .6$;
$R = 5.0$;
$n = 12.0$;
C is unknown.

1. Placing all the cells in *series*, we use formula (*b*),

$$C = \frac{se}{sr + R}.$$

Therefore, $C = \frac{12 \times 1.1}{12 \times .6 + 5} = \frac{13.2}{12.2} = 1.082.$

The resistance r' of the whole battery $= 12 \times .6 = 7.2$ ohms.

	Volts.
E. M. F. lost in battery $= C \times r' = 1.082 \times 7.2 =$	7.79
Volts lost in external circuit $C \times R = 1.082 \times 5 =$	5.41
The total E. M. F. = the sum	= 13.20

The above arrangement is shown in Fig. 34.

2. All the cells are placed in *parallel*. Using formula (*c*), we find

$$C = \frac{e}{\frac{r}{p} + R} = \frac{1.1}{\frac{.6}{12} + 5} = \frac{1.1}{5.05} = .21782.$$

Resistance of the whole battery $r' = \frac{r}{p} = \frac{.6}{12} = .05$ ohm.

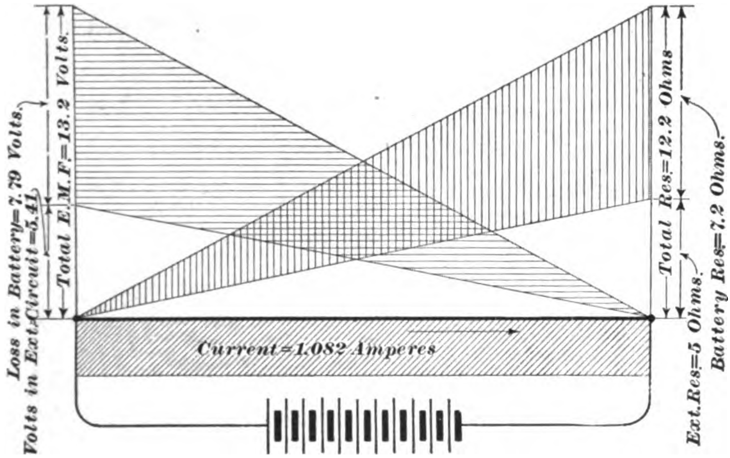


FIG. 34.

		Volts.
E. M. F. lost in battery	$= C \times r' = .217 \times .05 =$	.01
E. M. F. lost in external circuit	$= C \times R = .217 \times 5 =$	1.09
	Total E. M. F. = the sum =	1.10

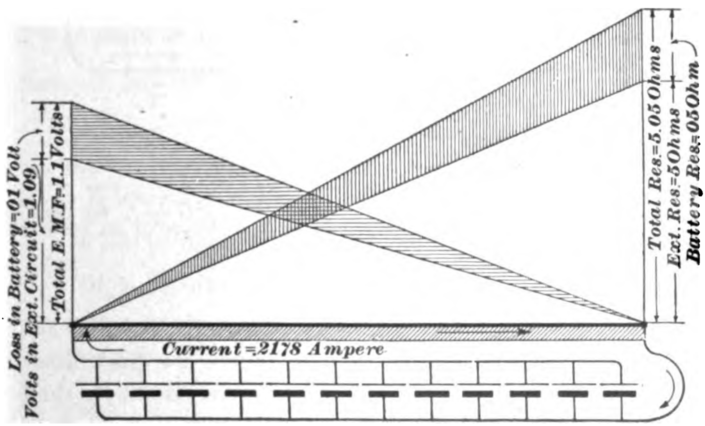


FIG. 35.

Fig. 35 shows the above arrangement.

3. Let the cells now be placed 4 in *series* and 3 in *parallel*. Then, $s = 4$, $p = 3$, and formula (a) now gives

$$C = \frac{se}{\frac{s \times r}{p} + R} = \frac{4 \times 1.1}{\frac{4 \times .6}{3} + 5} = \frac{4.4}{5.8} = .7586 \text{ ampere.}$$

		Ohms.
Resistance of the whole battery $r' =$	$\frac{s \times r}{p} =$	.8
Resistance of the external circuit $R =$		5.0
Total resistance =		5.8

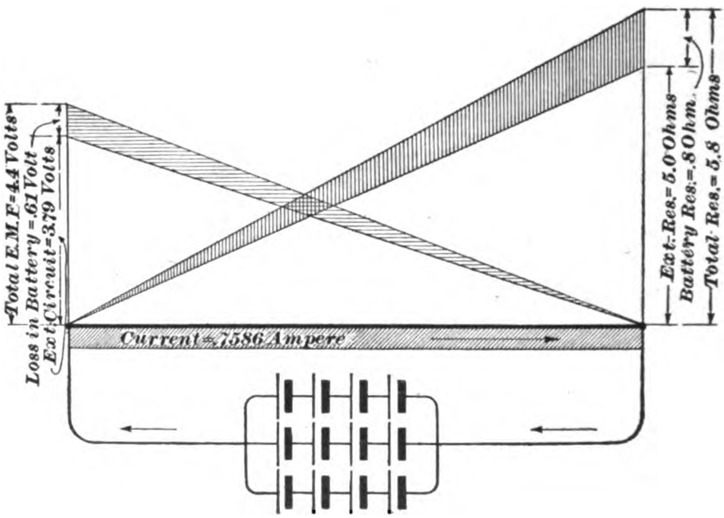


FIG. 36.

		Volts.
E. M. F. lost in battery	$= .8 \times .7586 =$	.61 nearly
E. M. F. lost in external circuit	$= 5 \times .7586 =$	3.79
Total E. M. F. = the sum =		4.40

The above arrangement is illustrated by means of Fig. 36.

With the external resistance of 5 ohms, we find that the greatest pressure is furnished to the external circuit by the first combination, as shown in Fig. 34, and the smallest pressure by the arrangement in parallel, as shown in Fig. 35. The loss of E. M. F. in the battery was much smaller in Fig. 35 than in

Fig. 34, and yet a smaller pressure was delivered to the external circuit, because the total pressure was only that of 1 cell. We also note that the battery resistance in Fig. 35 is far below that of Fig. 34, and this explains why the internal loss was less in the former instance, as this loss is a product of the current-strength in amperes and the internal resistance.

134. In looking at the formula (*b*), $C = \frac{se}{sr + R}$, it will be noticed that R, if very small in comparison with r, may be omitted and the formula will then read $C = \frac{e}{r}$, which means that, if the cells are placed in series, the voltage, amperage, and resistance will be simply those of *1 cell* if the *external* resistance is very *small* in comparison with the internal resistance. On the other hand, if the *external* resistance is very *large* compared with the internal, the latter may be omitted, and the formula will then read, $C = \frac{s\,e}{R}$; that is, the current-strength increases with the number of cells.

135. Summary. — Taking formula (*c*), $C = \dfrac{e}{\frac{r}{p} + R}$, under consideration, we find the conditions somewhat different. If R is so *small* in comparison with r' that it may be omitted, we have $C = \dfrac{e}{\frac{r}{p}}$, or, in other words, when all the cells are placed in parallel, and the external resistance is very small, the E. M. F. is the same as that of 1 cell, while the total resistance is reduced in proportion to the number of cells. If R is very *large*, $C = \frac{e}{R}$; the E. M. F. would then be that of 1 cell, and the resistance would correspond to the external resistance.

Recapitulating our deductions, we have:

If R is very *large*, compared with r',
$C = \frac{s\,e}{R}$, when cells are in *series*.
$C = \frac{e}{R}$, when cells are in *parallel*.

If R is very *small*, compared with r',
$$\begin{cases} C = \dfrac{e}{r}, & \text{when cells are in } \textit{series.} \\[2ex] C = \dfrac{e}{\frac{r}{p}}, & \text{when cells are in } \textit{parallel.} \end{cases}$$

We see, therefore, that *for a large external resistance the series arrangement is the more suitable, while for a large current, through a small external resistance, the parallel arrangement will be more serviceable.*

The arrangement in series is therefore always used in percutaneous applications and the arrangement in parallel in light and cautery work.

136. Arrangement for Maximum Current.—The question often comes up "how shall the cells be arranged to give a maximum current?" In answer to this it will not be necessary to show *how* this question may be solved, but suffice it to say, that calculations show that *a maximum current is sent through a given external resistance when this resistance is equal to that of the battery.*

If the external resistance is known, the internal resistance has to be so arranged as to be as nearly equal to the former as possible. The formula (*a*), $\frac{s\,r}{p}$, will help find the internal resistance of the battery.

It must be remembered that this arrangement is not the most *economical.* When the external and internal resistances are alike, it stands to reason that the losses in them must also be alike, and that of the total energy at disposal in the battery, one-half is lost in heating the latter and only 50 per cent. of the total energy made use of in the external circuit.

137. Economical Arrangement of Cells.—As the pressure required to overcome the internal resistance of a cell or battery is useless as regards the external circuit, that arrangement would appear to be the most economical which makes the internal resistance a minimum in comparison with the external circuit. This would not always be the most practical solution, as the question of time has also to be considered. In general, a compromise is therefore made and a certain maximum loss of, say, 10 to 15 per cent. allowed in internal circuit.

138. Arrangement for Quick Action.—When an electric current is rapidly stopped and started there comes another factor in play besides that of resistance. This factor is called self-induction, and is fully described in *Magnetism and Electromagnetism*. It may be compared with a momentary resistance; one of short duration that quickly comes and quickly disappears. Circuits that contain telegraph keys, bells, etc. are subject to this class of resistance and cannot be considered from the same point of view as a circuit in which a steady current is flowing. This subject cannot well be treated more fully here; it must suffice to say that circuits of this class, as a rule, demand cells arranged in *series* to give the desired quickness of action to the apparatus inserted in the circuit.

CLASSIFICATION OF ELECTROMOTIVE FORCES.

139. Variations in E. M. F.—Electromotive forces, as produced by various appliances, are alike in their tendency to start an electric current, but they are often very dissimilar in other respects. Some devices, as, for instance, a primary battery or a direct-current dynamo, produce electromotive forces that are practically constant in strength; again, in others, such as static machines, the E. M. F. is more or less variable, while finally, in alternators and induction-coils, we find the E. M. F. not only varying in strength, but also in direction, periodically changing from a positive to a negative E. M. F., or vice versa.

These variations may be very clearly shown graphically by means of a curve on cross-section paper, the method usually adopted being to let the *ordinates*, or vertical distances, represent the E. M. F., and the *abscissas*, or horizontal distances, represent intervals of time.

GRAPHICAL REPRESENTATION OF PRESSURE.

140. Direct and Continuous E. M. F.—To make the subject clearer, we will again use as an analogy the flow of water from a tank through a tube at a constant pressure. Let the pressure be 4.5 pounds per square inch, and the water in the tank be kept at a constant level. The conditions may then be represented by means of the diagram in Fig. 37.

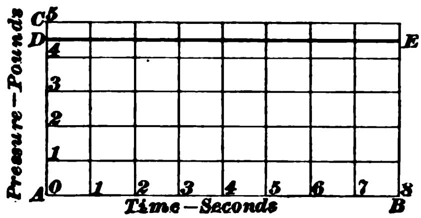


FIG. 37.

Here the vertical line *A C* at the left measures off the pressure in pounds, and the horizontal line *A B* indicates the time in seconds. The line *D E* is then laid off at a distance from *A B* corresponding to 4.5 pounds. The fact that the line *D E* is entirely parallel to *A B* proves that throughout the time of 8 seconds the pressure remained constant.

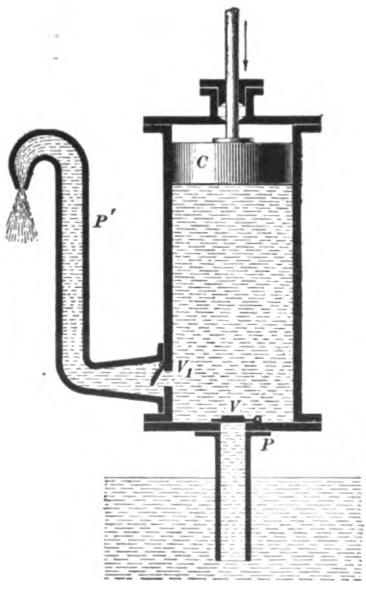


FIG. 38.

An E. M. F. acting in this manner would be called a *direct*, or *continuous*, E. M. F. and an electric current caused to flow by an E. M. F. of this class would be called a *direct* current, because it is caused to flow by an E. M. F. that tends to act in one direction only, as distinguished from an alternating E. M. F. that periodically changes direction. A direct E. M. F. need not necessarily be constant, in fact, it may vary between very wide limits.

A distinction is made between a direct E. M. F. or current that has an absolutely constant value during succeeding intervals of time and one that varies in strength. The first is called a *continuous* E. M. F. or current, while the latter may be either an intermittent or a pulsating E. M. F. or current.

141. Intermittent E. M. F. or Current.—An *intermittent* E. M. F. or current may be compared with the stream of water that would flow from the pump shown in Fig. 38. It is supposed that the piston *C*, during a time of 4 seconds, forces the water out through the valve V_1, into the pipe P', and that at the end of the latter the water is delivered at a pressure of 8 pounds per square inch.

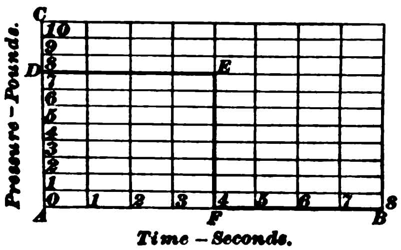


Fig. 39.

While the piston returns to its original position, which also takes place during the time of 4 seconds, water is flowing into the cylinder from the pipe *P* through the valve *V*. The action of the pump, so far as the pipe P' is concerned, is intermittent, and if it is required to show the action by means of a diagram, then Fig. 39 will

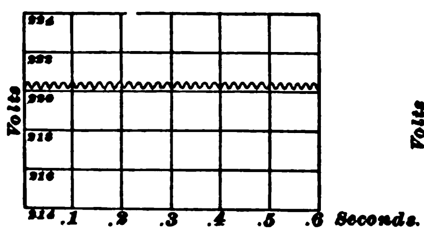


Fig. 40.

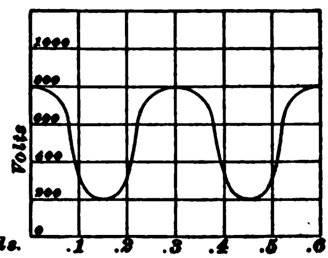


Fig. 41.

represent the conditions that exist during the time of 8 seconds. The line *D E* shows that the pressure in the pipe P' during the time of 4 seconds remained at a constant pressure of 8 pounds; at this point the pressure fell to zero and remained there during the next 4 seconds, while the piston was returning to its first position.

Examples of intermittent electric currents are found in those that flow from galvanic batteries through telegraph keys, electric bells, etc.

142. Pulsating E. M. F. or Current.—A *pulsating* E. M. F. or current is one that periodically receives a momentary increase in pressure without being interrupted and without changing direction. Figs. 40 and 41 give two examples of a pulsating current in the first of which the fluctuations are very small and in the latter amounting to a difference of 600 volts.

A fairly good imitation of a pulsating current may be made by means of a rubber-bulb syringe. If the latter, while continually subjected to the pressure of one hand, periodically receives an increase in pressure, a stream of water would flow through the orifice that would show a momentary increase in current-strength. The elastic walls of the bulb would assist in giving the fluctuations the wavy character shown in the two figures.

A dynamo with few coils in its armature would produce an E. M. F. of a somewhat similar nature; so would a voltaic battery, if its current were passed through an ordinary carbon rheostat, the resistance of which would change by rapidly varying the pressure on the regulating lever.

ALTERNATING E. M. F. OR CURRENT.

143. Alternating E. M. F.—An *alternating* E. M. F. is one that alternately changes in direction. In the form most frequently found it may be said to be an E. M. F. that constantly changes in magnitude and periodically in direction.

The following experiment may help in explaining the nature of an alternating E. M. F. or current. Let *A* and *B*, Fig. 42, be two rubber bulbs communicating with each other through the rubber tube *a*. The bulb *B* is supposed to be empty while *A* is filled with water. If, now, *A* is compressed, a stream of water will flow through *a* to the other bulb *B* in the direction of the arrow. We will call this a *positive* direction. When *B* is compressed, the current will change in direction and flow toward *A*; it will flow in a *negative* direction. By rapidly varying the difference in pressure between *A* and *B* a current of water will rapidly move forwards and backwards in the tube *a*. It would be an alternating current, and the bulbs *A* and *B*

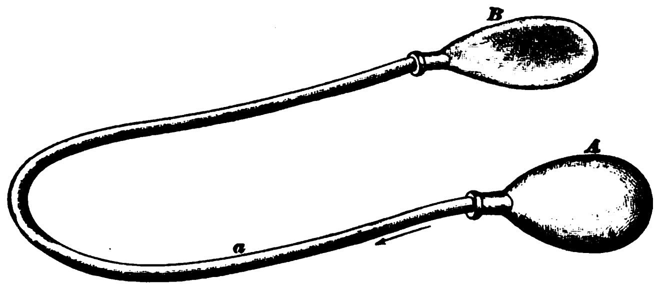


FIG. 42.

would periodically change their potential from positive to negative.

Fig. 43 shows a form of alternating E. M. F. which suddenly changes in direction, such as would be the effect if the E. M. F. that a voltaic battery impressed on a conductor were suddenly reversed by means of a commutator. The alternating E. M. F. most frequently found changes its direction more gradually, as seen from the curve in Fig. 44. Here the E. M. F. begins from zero at *A*, rises gradually, while acting in a positive direction, until it reaches *B*, where it has a maximum value of 500 volts; from this point the pressure begins to fall, still remaining positive, until at *C* it again reaches the zero-mark. In passing below this point the direction of the E. M. F. changes from positive to negative, and the maximun pressure is attained at *D*, whence it again begins to fall until point *E* is reached, when the E. M. F. once more is

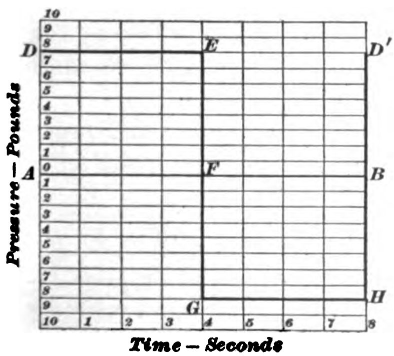


FIG. 43.

of zero value. Proceeding from E toward F, the E. M. F. is positive again, and from there follows a repetition of the curve as begun at A.

144. If the curves representing the E. M. F. on either side of the zero-line are exactly of the same shape, but acting in

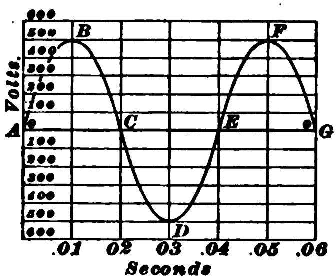


FIG. 44.

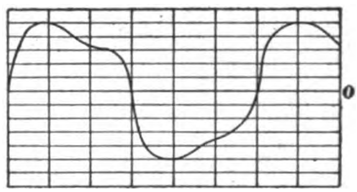


FIG 45.

opposite directions, the alternating E. M. F. is said to be *symmetrical.* Figs. 44 and 45 represent curves of symmetrical, and Fig. 46 a curve of *dissymmetrical* form, such as may be produced in the secondary coil of an induction-coil.

145. Sine Curves.—The curve shown in Fig. 44 is also called a **sine curve,** or **sinusoid,** and the E. M. F. which it represents is said to be **sinusoidal.**

The nature of a sine curve may be explained by means of Fig. 47 (a), (b), and (c). Let us suppose that a point a of (a) revolves around the point o with a constant velocity, so that the distances $a\,b$, $b\,c$, etc. are each covered during the time of 1 second. If the point a had been traveling in a direction at right angles to the line $a\,a_1$, for instance, along the line $a\,h$, the distance traveled along this line would at any time be directly proportional to the time during which the point a had been in motion. That is to say, during a time of 6 seconds, a would be at a distance $6 \times a\,b$ away from the line $a\,a_1$. But when the point a performs a

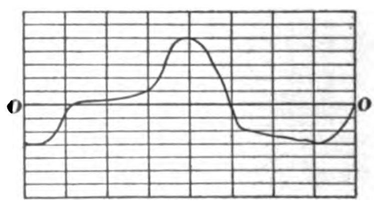


FIG. 46.

circular motion, as in (*a*), the conditions are entirely different. The distance between *a* and the line $a\,a_1$ is then no longer directly proportional to the time, but to the sine of the angle through which it has moved relatively to the line $a\,a_1$. For instance, when the point *a* has moved into the position *d*, and, therefore, through the angle $a\,o\,d$, its distance from $a\,a_1$ is proportional to the *sine* of this angle, or the line $d\,d_2$. Similarly, when *a* has moved to the point *f*, its distance from $a\,a_1$ is proportional to the sine $f f_2$, and so forth. If, now, the line $a\,a_1\,a_2$

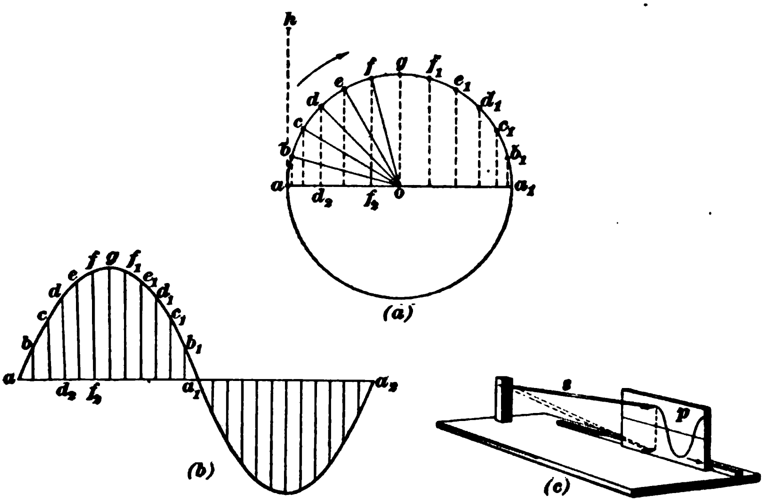


FIG. 47.

in Fig. 47 (*b*) is divided into a number of equal parts corresponding to the number of divisions of the circle in Fig. 47 (*a*), and vertical lines are erected from these points, the sines of the various angles may be laid off on these lines. Thus, $d\,d_2$ corresponds to the sine of angle $a\,o\,d$, and $f f_2$ to the sine of $a\,o\,f$, etc. As soon as the point *a* passes the position a_1, the values of the sines will be negative, and are laid off below the line $a\,a_1\,a_2$, in the manner already described.

When the various points *a*, *b*, *c*, *d*, etc., thus determined, are connected by means of a curved line, this line will constitute a sine curve. A sine curve is not necessarily limited to the form given in Fig. 47 (*b*), as it is evident that the relation between the length of the divisions on the line $a a_1 a_2$ and the sines will materially change the appearance of the curve. Thus, by bringing the said divisions more closely together, the curve will assume a more peaked form, while, on the other hand, if the divisions are put farther apart, the waves will appear more shallow.

A sine curve may be automatically drawn by means of a vibrating spring. If a long, flat spring *s*, in Fig. 47 (*c*), is fastened at one end and the other provided with a pencil, the latter will, while the spring vibrates, draw an approximate sine curve on a sheet of paper *p* moved under the pencil in a direction parallel with the center line of the spring.

146. Cyclic Alternating Currents.—If the curve which represents the E. M. F. of an alternating current is symmetrical on both sides of the zero-line, as the curve in Fig. 44; and if, further, the continuation of the curve is simply a repetition of the first part *A B C D E*, then the E. M. F. (or its resulting current) is called a **cyclic, periodic,** or **harmonic** alternating E. M. F. or current.

147. Alternations, Cycles, and Periods.—In speaking of a cyclic alternating current, each complete reversal of the E. M. F., or current, is called an **alternation;** in Fig. 44, for instance, three alternations are represented, as *A B C*, *C D E*, *E F G*; each alternation lasts, therefore, .02 of a second, and there are 50 alternations per second. Two successive alternations, that is, one positive and one negative wave, constitute a **cycle.** *A B C* and *C D E* together constitute one cycle, and the time required for its completion is called a **period;** in the present instance it is .04 second, and the E. M. F. represented by this curve would be said to have a period of .04 second.

148. Frequency.—The number of complete cycles which occur in 1 second is called the **frequency,** and this is indicated by the sign ∾. In the example cited above, the number of cycles which occur in 1 second is $\frac{1}{.04} = 25$, so this E. M. F.

would be said to have a frequency of 25 ∿, or 25 *cycles per second*. *Frequency* is the reciprocal of *period*.

149. Alternating Current.—The current-strength produced by this varying E. M. F. will not necessarily be proportional to the height of the E. M. F.; it will also depend on the rate at which the E. M. F. increases or decreases in value or changes from positive to negative. If the E. M. F. is continuous, or if the changes are so slow as to more or less avoid the introduction of self-induction, the value of the current-strength will keep step with that of the E. M. F. But when the rate at which these changes take place exceeds a certain frequency, the current will no longer be able to keep step with the E. M. F., but will lag behind and will reach various points in its own cycle a certain length of time *after* the impressed E. M. F. has reached similar points in its cycle. Fig. 48 shows the effect very clearly. Here *A* is the curve of the E. M. F., which would also be the curve of the resultant current, if the circuit were devoid of self-induction. The curve *B* shows the real strength of the current and the position of its maximum values as related to those of the E. M. F. We see here that the crests of the waves in curve *B* not only lag behind those of *A*, but also fail to reach the same height as those of the latter curve.

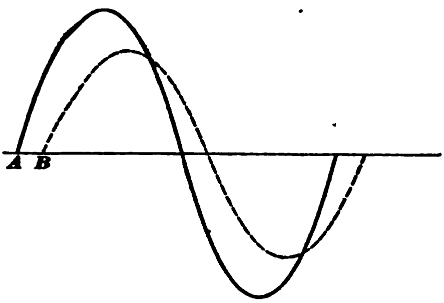


FIG. 48.

MAGNETISM AND ELECTROMAGNETISM.

NATURE OF MAGNETISM.

1. Introductory.—In studying *Direct Currents*, consideration was had merely of the flow of an electric current through a conductor and the variations it undergoes by changes in the material, dimensions, and temperature of the latter. In studying *Magnetism and Electromagnetism*, properties that show themselves external to the electric conductor, in the surrounding medium, are considered. On these phenomena are based the action of the induction-coil, the sinusoidal alternator, transformers, and also dynamos and motors. It is very important that the physician should carefully study the theory of these apparatus and thus gain a good understanding of their action, the more so as there is quite a difference in the character and effects of the currents delivered by these various appliances. The physician should therefore be able to determine in what cases one would be more beneficial than another, and this he will be unable to do unless he is entirely conversant with the special characteristics of each variety of current.

2. Magnetism and Electromagnetism.—Under *magnetism* we understand the property certain metals possess or are capable of possessing by means of which they are able to attract or repel other bodies with similar properties. We class these phenomena under *electromagnetism* when similar effects are produced by means of a conductor carrying an electric current.

About the real nature of these magnetic properties, science has been unable to tell us much more than it has about the nature of electricity. It is generally supposed that magnetism is electricity in rotation. Why certain metals, in preference to others, are able to show magnetic properties has not been ascertained. Science has, so far, only been able to formulate the laws under which these forces act and react. Iron, steel, nickel, and cobalt are those generally considered as **magnetic substances.**

3. Reaction Between Magnets.—In bringing two ordinary magnetic needles in proximity to each other we find they perform certain peculiar, but well-known motions. For instance, on attempting to bring their similarly marked poles opposite to each other, they will refuse such proximity, and a repulsion will take place, resulting in a partial revolution of either needle into new positions, in which the axis of both needles lie in one line, but with differently marked poles adjoining, as shown in Fig. 1.

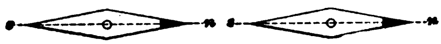


FIG. 1.

We come then to the conclusion that *the similarly marked poles of magnetic needles repel each other, and differently marked poles attract each other.*

In this country the marked end of a needle or bar magnet is called a **north pole,** the other end a **south pole,** and for the present these terms will be used without explaining their meaning.

4. Experiments With Magnetic Needle.—The knowledge thus acquired we will use for some further investigation of

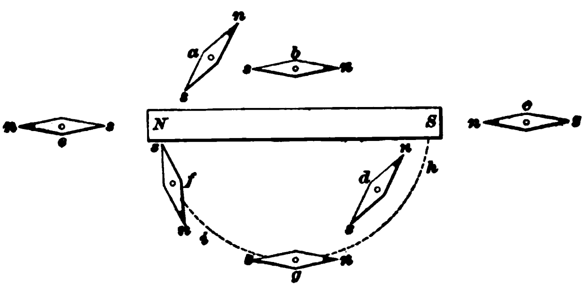


FIG. 2.

the immediate surroundings of a bar magnet, such as is shown in Fig. 2. On bringing a magnetic needle near its sides or ends, we notice that the position of the needle will vary considerably while it is moving along the sides of the bar.

In position *a* we find the south pole of the needle pointing towards the north pole of the bar, but making an angle of about 75° with the axis of the latter. Moving to position *b*, the needle places itself entirely parallel with the bar, and, on arriving opposite the end of the latter, at *c*, it has placed itself exactly in line with the longitudinal axis of the bar. In the latter position opposite poles are facing each other. Continuing this method of investigation, we arrive at the other side of the magnet and find there similar conditions; at *d* we have its north pole pointing towards the south pole of the bar, making an angle corresponding to that at *a*, and, continuing the circuit, we arrive at last at *e*, where the needle again places itself in line with the axis of the bar, but in this instance with its south pole opposite the north pole of the magnet. If the bar is round, we might, after placing the latter in a vertical position, move the needle in circular horizontal paths around it, and would find some invisible force constantly tending to deflect the needle into positions in which it always is pointing towards the axis of the bar.

5. We will now go a step further and follow a path from one end of the bar to the other, as indicated by the needle itself. Beginning at *f* and following the direction in which the north pole *n* is pointing, we arrive at point *g*, where the needle again is parallel with the bar, and, continuing, we find the termination of the path at *h*.

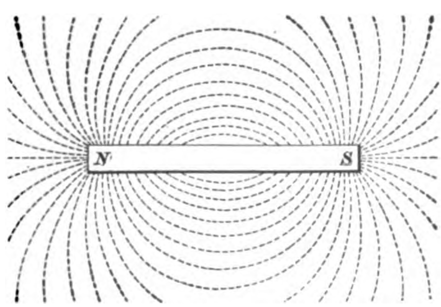


Fig. 3.

By placing the bar magnet on a sheet of paper and indicating, by means of a pencil, the path over which the needle has traveled, we will have drawn a line somewhat similar to the dotted line *h i* in Fig. 2.

In starting from other points, along the sides and ends of the bar magnet, numerous paths may be marked out, so that after awhile we would have a picture somewhat similar to Fig. 3.

A simple way to show the direction of these lines is to dust fine iron filings on a sheet of paper and place this over the magnet, with a plate of glass intervening, when, by gently tapping the glass, the iron filings will arrange themselves in lines corresponding to those of Fig. 4.

6. Lines of Magnetic Force.—*Faraday* made very extensive investigations of magnetism by means of such iron

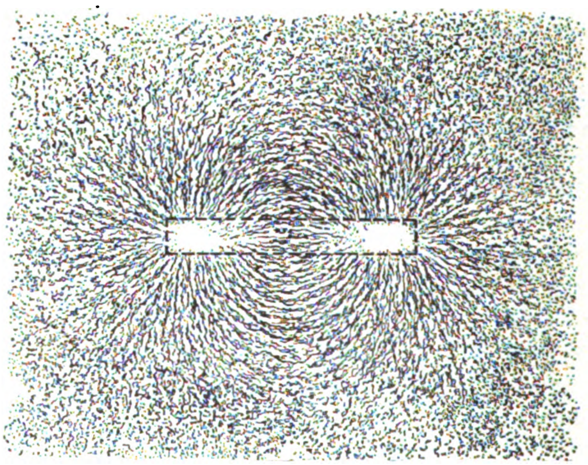


FIG. 4.

filings, and the lines which they traced were by him called **lines of magnetic force.** These lines show the direction in which the magnetic force is acting, and also indicate the strength of the force, as they are more numerous and closer together where the intensity of the magnetism is at its maximum. The whole collection of lines of force around the magnet is called the *magnetic field.* The lines of force in a magnetic field, when not disturbed, have only two qualities, those of attraction and repulsion. In order to make these lines produce an E. M. F., they must be intersected by some conducting material, and to obtain an electric current the conducting material must form a circuit.

7. **Magnetic Field.**—Of course these lines have no actual existence. It is well to remember this, as diagrams similar to Fig. 3 are often understood to mean that the magnetism acts along these lines only, and nowhere else; that is to say, that between these lines the magnetic field is neutral. Evidently this is a misconception; there are no variations in the field as sudden as this, but, on the contrary, a gradual decrease towards the exterior parts of the field.

8. When a magnetic field exists between two magnetic bodies, we have to imagine a certain stress in said field, a tendency to draw the bodies together along the lines of force. We have further to suppose that this attraction is not carried on by means of the surrounding air, but by the aid of the all-pervading *ether*, which also surrounds each individual molecule of the two bodies.

9. **Magnetic Flux.**—Though we do not know for certain that the electric current actually flows through a conductor, we use this convention as a convenience and determine its direction of flow by investigating its influence on a magnetic needle, as will be shown further on.

In the same manner we speak of the magnetic lines of force as flowing from pole to pole, thus indicating the direction of the **magnetic current,** or **flux,** and also here determine the direction by means of a freely suspended magnetic needle. Thus, in Fig. 2, the needle while moving from position *f* to *h*, was traveling with the lines of force.

When a freely-suspended magnetic needle is standing or moving in a magnetic field its north pole will always indicate the direction in which the lines of force at that place are flowing; in fact, we may imagine these lines to *enter the needle at its south pole and leave it at its north pole.* Applying this rule to Fig. 1, the lines of force would come from the extreme left, enter the first needle at its south pole, leave it again at its north pole, to enter the south pole of the other magnet, and so forth. This rule forms the foundation for all the following experiments, and must be kept clearly in mind.

10. Interactions Between Lines of Force.—We have seen that when unlike poles of two magnets are opposite each other, an attraction takes place. Now, the condition of the magnetic field between these poles is somewhat similar to that which would prevail if the lines of force were replaced by a series of rubber strings under tension, which, to make the similarity complete, should also have a tendency of mutually repelling each other in a lateral direction.

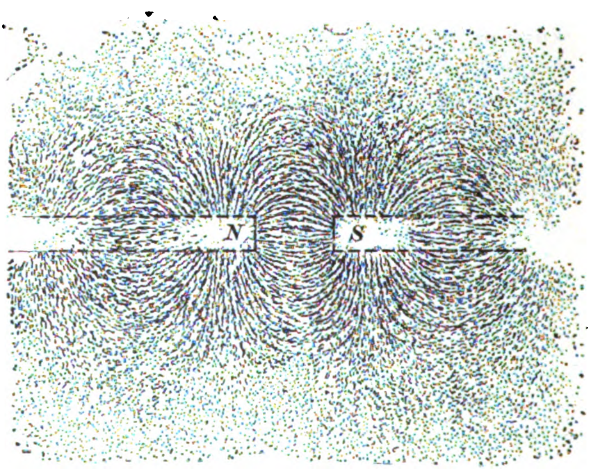


FIG. 5.

Lines of magnetic force running in the same direction have this tendency of repelling each other, while between lines running in opposite directions an attraction takes place. We shall see further on that these interactions also take place between two conductors through which electric currents are flowing.

Figs. 5 and 6 illustrate the interactions between lines of force in two magnets. If, as in Fig. 5, the adjoining poles are of opposite polarity, the lines of force near each of the poles will, before the latter are brought close together, be traveling in opposite directions; but if the bars are so close that an interaction takes place, the lines of force will attract each other and unite. The contracting tendency of the lines will then begin and the two poles will attract each other.

In Fig. 6 the conditions are reversed, as here two similar poles are facing each other, from both of which lines of force are emanating in the same direction. A repulsion will therefore take place and the lines of force will turn away at right angles to the axes of the two magnets. This repulson of the

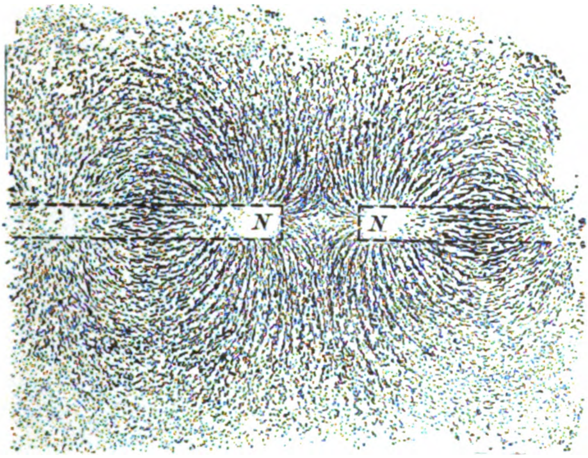


Fig. 6.

lines of force will interact on the molecules of the bars and will also cause a repulsion of the latter.

11. Magnetic Circuit.—We have now seen how in a magnet there is a certain flow of magnetism issuing from its north pole, whence it proceeds in curved paths through the surrounding space along the sides of the bar to its south pole, where it again enters and then traverses the whole length of the magnet. As there is neither end nor beginning to this flow, it constitutes a closed path or circuit, and is therefore called a **magnetic circuit.**

It has also been shown how a freely-suspended magnet, when in a locality where lines of force are passing, will place itself so that its longitudinal axis coincides with the lines of force and so that it points with its north pole in the direction in which the lines of force are traveling. Finally we found that unlike poles attract and like poles repel each other.

12. Terrestrial Magnetism.—There yet remains one subject with which we have to deal before we proceed any further, and that is the magnetism of the earth. It is a familiar fact that the earth itself constitutes an immense magnet, with a north and south pole, and lines of force traveling through its interior as well as along its surface and through space. The presence of these lines of force has been of great benefit to

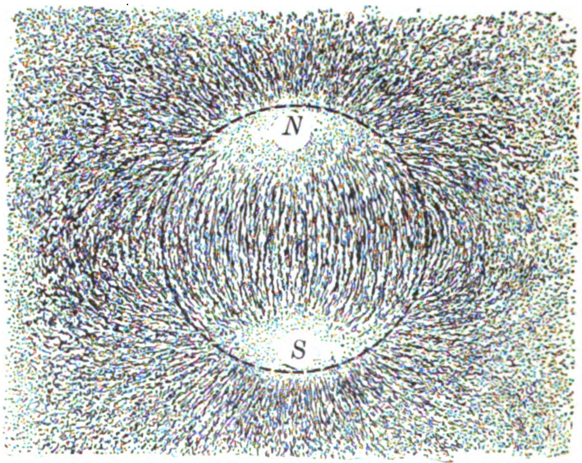


FIG. 7.

travel both on land and sea, in making the use of a compass possible.

In Fig. 7 we find a representation of the form which the lines of force will assume in traveling from pole to pole, and also the directions in which they will move. When applying the information so far derived concerning the position a freely-suspended magnetic needle will occupy while situated in a magnetic field, we come to a conclusion which is not a matter of general knowledge. The magnetic needle of the mariners' compass or any other compass will, as we all know, point towards the terrestrial north pole, or very nearly so, depending on the longitude of the place where it is situated. The lines of force will therefore enter the needle from the south, pass through it and proceed towards the north. But it has previously been said that the lines of force *leave* the north pole of the magnet; evidently, then, the lines of force coming from the south pole towards the needle must come from a north pole, and we therefore come to the conclusion that the *terrestrial south pole* must be a *magnetic north pole* and vice versa. The magnetic south pole does not coincide with the earth's north pole, but is about 1,000 miles to one side of the latter.

MAGNETIZATION.

13. Two questions will now suggest themselves, to which we will have to find an answer, viz., (1) *Why does a body of iron or steel under certain conditions change from a neutral to a magnetic condition?* (2) *If a piece of steel is magnetized in one of different ways, has it had imparted to it a certain magnetic force not previously existing in it, or, if not, where does this force come from?*

14. Difference Between Electricity and Magnetism. Before attempting to answer these questions let us first consider an important difference between electricity and magnetism. If, for instance, a conductor is charged with electricity and is brought in contact with another conductor, it will give up part of its charge, as will be shown in *Electrostatics.* On discharging and charging the second conductor again and again, the first conductor will finally have given up all of its charge, and both will be neutral.

If this experiment is repeated with a magnet and one or more pieces of steel, the result will be entirely different. We can, for instance, magnetize and demagnetize one piece of steel any number of times, or we can magnetize any number of steel pieces with the same magnet; the result will be the same, that is, the magnet will not give up any of its magnetism or grow weaker. How, then, shall we explain this apparent inexhaustible supply of magnetism?

15. Molecules.—To give an explanation of this phenomenon we have to go to the physical foundation of all matter—to the molecule itself. The exact form of the molecule is not known, but every indication tends to show that it is more or less globular in form, perhaps slightly elongated. It appears that in a magnetic metal every molecule is in itself a magnet, very much constituted as the globe on which we live. But though we speak of molecules as being magnetic, we must understand this to mean that in reality it is the ether, enveloping each molecule, which exerts the magnetic attraction or repulsion, and not the molecule itself. It was already shown that this was the case with magnets in general, and it also holds good as regards the earth itself. We must therefore imagine each molecule to have its own north and south pole and its neutral equator.

Having this clear in mind, let us now see what are the positions of the molecules in a neutral piece of iron. We have seen that these molecules already are magnetic, and it is therefore of interest to see why it is that they do not show any external magnetism, and how they may be made to exhibit such magnetic effects. When not disturbed by external influences, the magnetic properties of the molecules of a neutral piece of iron are neutralized by the short circuits established between the molecules of the iron.

16. Interaction Between Freely-Suspended Magnetic Needles.—On holding a magnet near an ordinary magnetic needle, the latter will respond to every motion of the former and occupy any position desired. With *two* magnetic needles in close proximity to each other, as shown in Fig. 1, this is no longer the case; they will refuse to move out of line with each other until compelled to do so by a superior force. This interaction is clearly shown by means of Fig. 8, where the needles in position (*a*) are placed exactly as those shown in Fig. 1, and therefore mutually react on each other so as to keep their axes in line. In this and the following

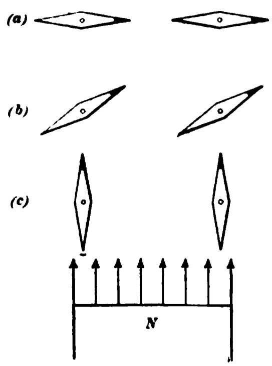


FIG. 8.

figures, the north pole of a needle will be designated by a black tip, so as to avoid confusion of letters.

We will now suppose that a strong magnet N is having its north pole turned towards the needles at (a), and that the latter are gradually brought closer to the magnet. In position (a) we find that the magnet N is unable to alter the relative positions of the needles; they stick stubbornly to each other. In position (b) the directing force of N has increased so much that they have been obliged to yield and to swing into new positions. The angle which they now form with the positions

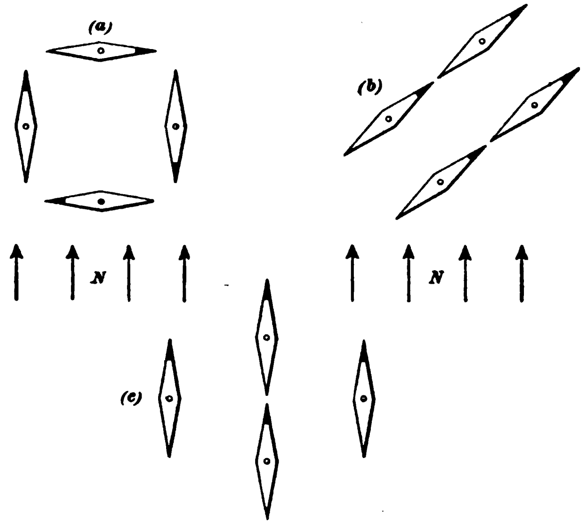


FIG. 9.

they at first occupied will increase on approaching the magnet, until suddenly they will cut loose from each other, and, after violently vibrating back and forth, place themselves in position (c). But that they are holding this position against their inclination is shown by the fact that, on removal of the magnet N, they immediately return to the first position (a).

17. Increasing the number of needles to four, the conditions are somewhat different, as there are *various* stable combinations which they now may make. Let Fig. 9 (a) represent one such combination. It is seen that this is a very stable one, and that it will take quite an effort for the magnetizing force N to break it up. On succeeding in doing so, the needles do not yet surrender, but effect an arrangement as indicated by Fig. 9 (*b*). Finally they are compelled to also give up this combination and to submit entirely to the directing force of N, as shown at Fig. 9 (*c*).

18. Various Stages of Magnetization.—These three combinations, as shown in the last figure, illustrate very clearly, on a small scale, the three stages which have to be gone through in order to magnetize a bar of magnetic material, such as steel, for instance. There is first the **initial** stage, represented by Fig. 9 (*a*). Here it takes relatively quite an effort to effect magnetization, or to secure the required arrangement of the molecules of the iron, that is, to cause the needles to deviate from their original positions; but no sooner is the magnetizing force withdrawn than the needles at once return to their first positions. On substituting molecules in place of the needles, we come to the conclusion that on exposing the steel bar to a relatively weak magnetizing force, no lasting effects will be produced; the molecules will swing back again after the magnetization stops, and the bar will remain neutral.

19. Residual Magnetism and Saturation.—On increasing the magnetizing force until the second combination has been effected, we have gone through the second stage of magnetization, as shown at Fig. 9 (*b*). Here the molecules have succeeded in making a new and stable combination, and when now the magnet N is withdrawn, the bar will retain its magnetism, and we have passed through the stage where **residual magnetism** is effected.

If the magnetizing force is increased so as to carry us beyond this stage, we will pass through the third stage, as represented by the combination in Fig. 9 (*c*), where **saturation** takes place. But we have already seen that this, as well as the variations in the first combination, are not of a stable character. The result will therefore be that after the magnet N is withdrawn, the molecules will return to the positions occupied at the end of the second stage, and that the magnetic strength there attained will be all that finally remains.

20. Molecular Rearrangement.—On multiplying these groups of four, we would have a combination somewhat similar to Fig. 10 (*a*), where the magnetic needles are replaced by figures which may represent molecules and on which the black tips signify north poles. We notice that the molecules are all magnetically interlocked with each other, forming stable combinations which are difficult to break. The diagram may represent a small particle of steel while in a neutal condition and exposed to a weak magnetizing force *N*. On increasing the latter the molecules will break their connections in order to turn around, so as to let their north poles point more in the

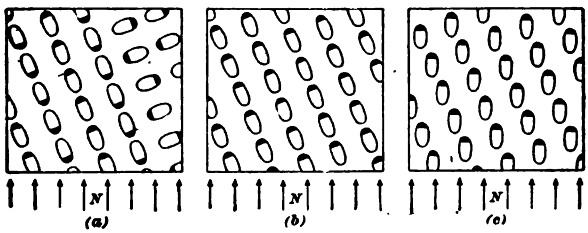


FIG. 10.

direction of the lines of force proceeding from the exterior magnet *N*; at the same time they will carry out new combinations of closed circuits, as shown in Fig. 10 (*b*).

A further increase of the magnetizing force will compel the molecules to again break their combinations and to stand exactly parallel with the external lines of force *N*, as represented in Fig. 10 (*c*); the steel is now *saturated* with magnetism. As already shown, they will not remain in these positions when magnetization ceases, but will return to the combinations of Fig. 10 (*b*), which represents *residual* magnetism.

21. Induced Magnetism.—In all the experiments so far considered, we have magnetized bars or needles by means of another magnet, without actual contact. Magnetism effected in this manner is said to be **induced.** It must now be evident from the previous explanations that no attraction or repulsion can take place between a magnet and a neutral body made of a magnetic substance, before the molecules of that body have become arranged in the required manner—that is, not before the molecules have been compelled to break their combinations and place themselves in line with the inducing lines of magnetic force.

22. Hydraulic Analogy.—These interactions between molecules and an external magnet may perhaps be made a little clearer by an analogy from hydraulics. Let *a* in Fig. 11 be a short tube situated in a tank *T* filled with water. The tube has in its interior a propeller *p* constantly revolving in such a manner that it will cause the water to flow in the direction indicated by the arrows. The tube is free to revolve around the point *b*, and is provided with a small vane *v*. We may consider this as a fair representation of a molecule with its surrounding lines of force.

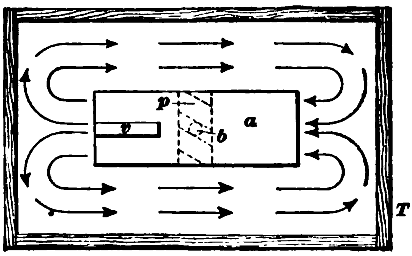


Fig. 11.

Let us place four of these tubes in a pipe *P*, shown in cross-section in Fig. 12 (*a*). They are all free to revolve around the points *b*, but will place themselves so as to constitute a closed circuit. Evidently there is a current constantly flowing in a circular path, from tube to tube, but there is no evidence of this outside of the tube *P*. We have here a condition similar to that of a piece of steel before the molecules of the steel have been rearranged by some external influence so as to exhibit the properties known as magnetization.

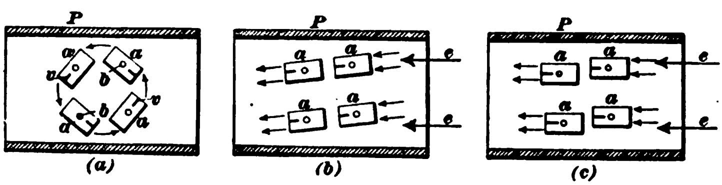


Fig. 12.

On now sending a current of water through the tube from the outside, in a direction indicated by the arrows *e* in Fig. 12 (*a*), the tendency of the current will be to deflect the tubes by means of the vanes *v* so as to send their currents in the same direction as that of the external current. If the latter is strong enough, it will be able to compel the tubes to occupy positions similar to that of Fig. 12 (*b*), which would correspond to the second stage of magnetization, where the induced magnetism is residual.

If the current-strength is increased still more, the tubes will be obliged to also give up these positions, and will then stand as in Fig. 12 (*c*), which corresponds to the condition of a saturated magnet.

When we divert the external current *e*, the tubes will return to the positions shown in Fig. 12 (*b*), and a current will now flow constantly through the tube, corresponding to the state of a substance in possession of residual magnetism. What we now have accomplished is to make an apparently neutral tube eject a constant stream of water, after first having sent an external guiding stream of water through it.

23. Examples of Magnetization.—We are now in a position to put our theories to a practical test and find an explanation for phenomena which have been familiar to us, but not understood. Let us, for instance, consider what takes place when a steel bar is being magnetized by a permanent magnet. It is an old and well-known method to stroke the bar with the magnet in a certain manner, and we are now able to see what the resulting polarity will be and why certain precautions must be taken.

In Fig. 13 we have a steel bar *B* to be magnetized by means of the bar magnet *M*. In the illustration the north pole of the bar magnet is placed at the middle of the bar and we see the lines of force proceeding from the magnet into the bar, where they divide and proceed both to the right and left, later to return to the magnet through the air. As the molecules in the bar must face with their north poles in the directions of the lines of force, we find one-half of the molecules facing in an opposite direction to that of the other half, and we will therefore find a north pole at either end of the bar, with a south pole at the middle. A bar magnetized in this manner is said to have **consequent poles.** It is evident that matters will not be any better by moving the magnet back and forth, as the magnetism which is induced by one stroke will be reversed by the return-stroke.

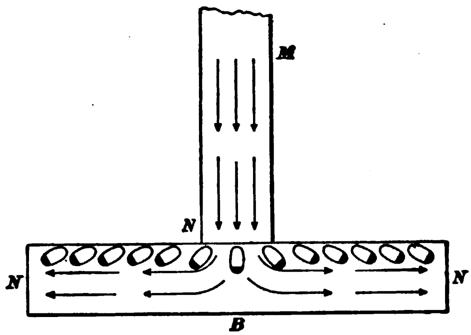


FIG. 13.

We will therefore have to change this method and proceed as indicated by Fig. 14. Here the magnet is moved from right to left, where it leaves the bar to return through the air to the starting point. During this manipulation the molecules will have placed themselves with their north poles towards the right, and their south poles towards the left, and the bar will therefore be magnetized so that its north pole is on the *right* side, and its south pole on the *left* side.

Fig. 15 proves that it is immaterial in which direction the magnet is moved, as in this instance the latter has been moving from left to right and then returned through the air. The bar has now a north pole on the *left* side. Of course, this stroking has to be repeated on the lower side of the bar.

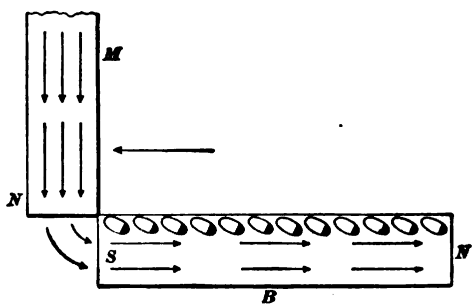


FIG. 14.

24. It will be unnecessary here to enter more into detail of the various kinds of magnetization, but, to make the examples complete, we will later on consider how magnetism may be induced by means of the electric current.

At the present stage it should no longer surprise us why, when a magnet is broken into smaller parts, each of the latter should be an independent magnet, with its own north and south pole. In fact, we can see, when looking at Fig. 14, that it should be possible to continue this breaking up of the bar into the smallest fragments and still find complete magnets of diminutive size. There is no such thing as a magnet having but one pole.

25. Effect of a Weak Inducing Magnet.—We saw, when Fig. 9 (*a*) was described, that the molecules during the initial stage of magnetization adhered rather tenaciously to one another so long as they were able to maintain their closed circuits. It would therefore appear that, if these combinations could be broken up by other means than an inducing magnet, so that the influence of the latter would simply be a guiding one, it should be possible to effect a strong magnetization with a weak inducing magnet. This has been found to be the case, and there are several methods by means of which this may be accomplished. Under these circumstances the rather weak inducing influence of the terrestrial magnetism may be used with advantage.

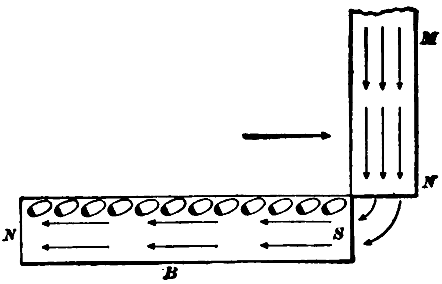


FIG. 15.

In Fig. 7 we saw the general direction of the earth's lines of force, and by means of this illustration we will be able to determine how a bar that is to be magnetized by the earth should be placed, as shown in Fig. 15, in order to be under a maximum inductive influence, and also be able to foretell the polarity of such a bar.

26. Disconnection of Molecules.—The disconnection of the molecules may be secured in four different ways. (1) *By setting the molecules into vibration.* This is accomplished by tapping the end of the bar with a wooden mallet while holding the former in a vertical position. (2) *By increasing the lateral* *distance between the molecules*, which is attained by subjecting the bar to a tortional strain. (3) *By increasing the longitudinal distance between the molecules*, as effected by elongating the bar. (4) *By exposing the bar to heat*, when the result is twofold. Not alone are the distances between the molecules increased all around, but the latter are also set vibrating at a constantly increasing rate.

A bar magnetized by any of these methods will, if situated north of the equator, have a north pole at its *lower* end, because the terrestrial lines of force pass downward in northern latitudes.

THE MAGNETIC CIRCUIT.

27. Length of the Magnetic Circuit.—The length of a magnetic circuit represents the average lengths of all the lines of force measured from where they pass out from the north pole along their circuit through the surrounding medium to where they enter the south pole, plus their length in the magnet. *In a short bar magnet*, the length of the magnetic circuit may be exceedingly large and difficult to measure, because a great many of the lines of force will travel a long distance before entering the south pole. Whereas, *in a longer bar, bent into the shape of a horseshoe*, the lines of force pass out from the north pole and immediately enter the south pole, thus making the average length of the magnetic circuit comparatively short and easy to determine.

28. Direction of Lines of Force.—*Lines of force can never intersect each other.* When two opposing magnetic fields are brought together, the lines of force from each will be crowded and distorted from their original direction until they coincide in direction with those opposing them, and form a resultant field. The direction of the lines of force in the resultant field will depend upon the relative strengths of the two opposing magnetic fields.

29. Similarity Between Magnetism and Electricity. There are a great many points of similarity between the flow of magnetism and that of electricity. Air is a medium that offers great resistance to both, although less to magnetism than to electricity. Magnetism will penetrate air more readily than will electricity. Metals like iron and steel are very readily penetrated by magnetism. When one of these metals is present in the magnetic circuit, the magnetic flux leaves the air almost entirely, and flows through the metal. The metallic body will then, for the time being, become a magnet with a south pole where the lines of force enter it, and a north pole where they pass out. In Fig. 16, *A* is a permanent magnet

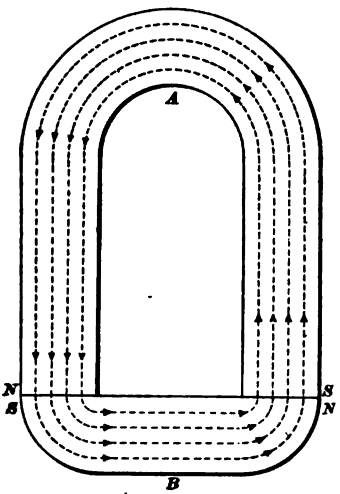


FIG. 16.

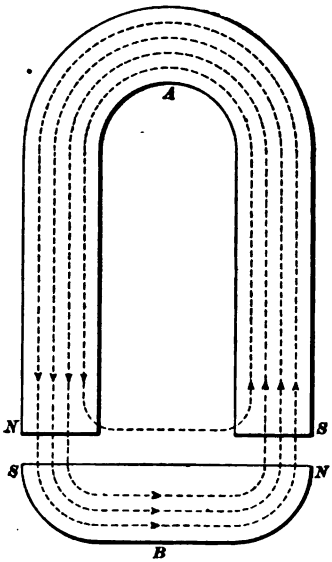


FIG. 17.

and *B* a piece of iron called an armature, which is placed across the poles of the magnet. The lines of force are seen to continue their path through *B*, making a magnet of it, while the armature in return greatly reduces the resistance of the circuit.

30. Reluctance and Magnetomotive Force.—Resistance to the flow of magnetism is called **reluctance.** Though at first glance reluctance may seem to be an exact counterpart of the resistance of electric circuits, there is yet a great difference between them. In an electric circuit the *resistance* in ohms of a given conductor is a constant, so long as the temperature remains the same, no matter how great an amount of current may be sent through it. In a magnetic circuit the reluctance does *not* remain the same, but increases with the density of the magnetic flux, first slowly, but later on almost in direct proportion to the increase of magnetization.

When the magnetic flux is weak, the reluctance of the air may be a thousand times greater than that of iron, but when the flux is increased to a high density, the reluctance of the iron will increase until it is very nearly the same as that of air. On the other hand, we find that the flux is proportional to the force causing it to flow, here called **magnetomotive force,** and inversely proportional to the reluctance. We have, therefore, practically a parallel to Ohm's law for the electric current, and we may write the law as follows:

$$\text{magnetic flux} = \frac{\text{magnetomotive force}}{\text{reluctance}}$$

The unit of *magnetic flux* is called the *weber;* the unit of *magnetomotive force* is called the *gilbert;* and the unit of *reluctance* is called the *oersted.*

The last formula can therefore also be written in this form :

$$\text{weber} = \frac{\text{gilbert}}{\text{oersted}}.$$

31. The source of the magnetomotive force will be considered later on ; at present we will consider other points of similarity between electric and magnetic currents. In an electric circuit the resistance depends on the substance of which the conductor is composed, on the length of the conductor, and its cross-sectional area ; the magnetic flux is also dependent on the substance or substances that constitute the circuit, the length of the circuit, and the area of the conductor. To decrease the resistance of a wire, its length may be reduced or its cross-sectional area increased. In the same manner the reluctance of a magnetic circuit may be decreased.

The sectional area of a magnetic circuit at any point in a magnet is the area of a plane through which the lines of force pass, the plane being taken perpendicularly to the direction of the lines at that point. The sectional area of the magnetic circuit outside the magnet is an indeterminate quantity, because the lines of force spread apart and diverge in all directions before entering the south pole. But where the lines of force have only a small air-gap to pass across, the tendency to spread apart will be less, and the sectional area of the magnetic circuit may be taken as the area of the polar face. For example, the sectional area of the magnetic circuit in a bar magnet 5 inches wide and 25 inches thick is $5 \times 25 = 125$ square inches.

32. Classification of Magnetic Circuits.—There are three kinds of magnetic circuits:

1. A *non-magnetic* circuit, in which the flux has to complete the whole circuit through air, copper, or other non-magnetic materials. (See Figs. 24 and 25.)
2. A *closed magnetic* circuit, in which the flux completes its whole circuit through iron or steel. (See Fig. 16.)
3. A *compound magnetic* circuit, in which the flux passes consecutively through iron or steel and non-magnetic materials, as air, wood, etc. (See Fig. 17.)

33. Magnetic Quantity and Density.—The *amount*, or *quantity*, of *magnetism* is expressed by the total number of lines of force passing along the magnetic circuit.

Magnetic density is the number of lines of force passing through a unit area measured perpendicularly to their direction.

The length of the magnetic circuit does not affect the magnetic density in a circuit, so long as the total number of lines of force remains unchanged.

To find the magnetic density per square inch, when the sectional area of the magnetic circuit and the total number of lines of force is known:

Rule.—*Divide the total number of lines of force by the sectional area of the magnetic circuit in square inches.*

Example.—If after measuring the magnetism in a straight-bar magnet ½ inch square and of any length, the total amount of magnetism at the middle of the bar is found to be 25,000 lines of force, what is the magnetic density in the bar?

Solution.—The magnetic density in the bar is $\frac{25,000}{.5 \times .5} = 100,000$ lines of force per square inch. This is equivalent to saying that 100,000 lines of force would pass through the magnet if its sectional area were increased to 1 square inch and the lines of force were increased in the same proportion.

MAGNETIC UNITS.

34. To facilitate a connection between the electrical and magnetic forces, a system of magnetic units has been adopted, based upon the *absolute*, or C. G. S., system of measurements, in which C. stands for centimeters, G. for grams, and S. for seconds.

A *unit magnetic pole* is one of such strength that, if placed at a distance of 1 centimeter from a similar pole of equal strength, it would be repelled with a force of *1 dyne.*

One line of force, or a *unit line of force*, is one of such strength that if a unit magnetic pole be placed upon it, the pole will be urged along with a force of 1 dyne.

A magnetic field of *unit density* is one in which every square centimeter area is cut by 1 line of force. Therefore, a magnetic field of unit density represents a condition wherein 1 dyne of force acts upon each unit pole of the magnet.

The force, in dynes, acting upon a magnetic pole placed in a magnetic field, is equal to the strength of the pole, in polar units, multiplied by the density of the magnetic field at that point.

ELECTROMAGNETISM.

35. When we considered the conditions of a magnetic molecule, it was found to be in possession of a magnetic field, or of lines of magnetic force, and the properties of magnetism and magnets, so far described, depend on the properties of these molecules with their inherent magnetism. If this were the only source of magnetism, electricity would never have been able to reach the preeminent position it occupies today; but, happily, means for providing an inexhaustible supply of magnetism, of an intensity hitherto unheard of, were found when electromagnetism was discovered. The phenomena of electromagnetism will now be considered.

36. If a freely-supported magnetic needle is placed under a conductor in the position indicated in Fig. 18, it will, as soon as a current of electricity is sent through the conductor, turn in the direction indicated by the arrows and tend to place itself at right angles to the conductor, its angular motion depending on the strength of the current. If the *conductor* is free to move and

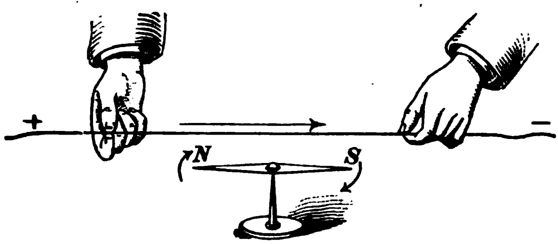


FIG. 18.

the *needle* is stationary, the conductor will move in a direction opposite to that indicated by the arrows. If both needle and conductor are free to move, the action will be mutual, each moving in a direction opposite to that taken by the other. In other words, *an electric current and a magnet mutually exert a force upon each other, and this force is always exerted at right angles.*

MAGNETIC FIELD OF ELECTRIC CONDUCTORS.

37. Magnetic Forces.—In looking for an explanation of this phenomenon, our first impulse would be to examine, if possible, the immediate neighborhood of an active conductor, to find whether the conditions existing previously have been changed since a current began to flow. On passing the conductor up through a hole in a piece of cardboard and sprinkling iron filings on the latter, we find that they will arrange themselves in concentric circles around the wire, as shown in Fig. 19. It makes no difference if the cardboard is moved along the conductor, the effect is the same anywhere along its entire length; neither is the phenomenon limited to the immediate neighborhood of the conductor; the effect can, in fact, be traced, under proper conditions, at a distance of miles away from a conductor. A practical example of this is seen in wireless telegraphy.

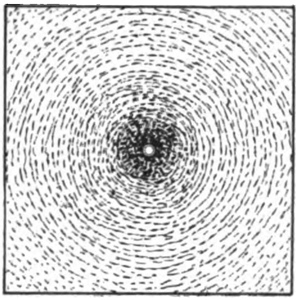


FIG. 19.

38. Magnetic Whirls.—Here we have again the lines of magnetic force, found to exist in and near magnets, but in a somewhat different form. We must imagine that the space surrounding a conductor is filled with innumerable magnetic whirls, all revolving in the same direction; these whirls are very close together near the conductor, but farther apart as their distance from the conductor increases. Fig. 20 will give a general idea of the position these magnetic whirls occupy relative to the conductor. It must be understood that part of the electric energy supplied to the conductor is utilized not

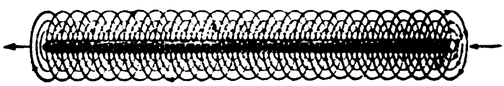


FIG. 20.

alone in setting up these magnetic whirls but also in maintaining them. If we again resort to the rubber rings as an illustration, we can understand that these whirls, like extended rubber rings, tend to counteract an attempt to extend them and enlarge their diameters, and that, after they are in an extended condition, an effort is required to maintain them in that position, their tendency being to contract themselves into the shape of small rings resting in the conductor.

To carry the illustration still further, we may suppose that an increase of current-strength will result in an increase of the diameter of the existing circular lines of force at the same time that new lines of force will be sent out from the conductor, the result being that there will be an increase of whirls per unit length. The *starting* of a current will therefore be followed by a spreading out of these whirls; while, on the other hand, the *stoppage* of the current will result in an immediate return of all the whirls to their original starting place in the conductor.

39. Direction of Magnetic Whirls.—It was stated above that these magnetic whirls were all revolving in a certain direction; it must here be added that the direction of the current in the conductor always stands in a certain relation to the direction in which the magnetic whirls rotate, so that by knowing the direction in which one of the two factors is moving, the direction of the other can always be determined. Considering these whirls as made up of circular lines of magnetic force, we can now see why the active conductor should have an influence on the magnetic needle, as was shown to be the case by means of Fig. 18, and it now remains to find in which direction the lines of force are moving when the current in the conductor is flowing in various directions.

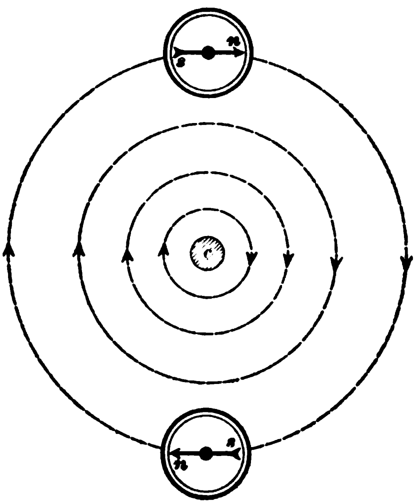


FIG. 21.

If we imagine a current to be flowing from the observer towards and into the conductor *c*, Fig. 21, it will be found that the lines of force travel in the direction indicated by the arrows, and as the magnetic needle always points with its north pole in the direction in which the lines of force are traveling, it follows that a magnetic needle, if placed above the conductor, would point to the right, and if below to the left. From this w deduct the following:

Rule.—*If the current in a conductor is flowing away from the observer, then the direction of the lines of force will be around the conductor in the direction of the hands of a watch.*

A simple method for remembering the connection between the lines of force surrounding a conductor and the direction of the current in the latter, is the following: Imagine an ordinary nut *a*, Fig. 22, to represent the lines of force, and a bolt *b* to be the conductor, both nut and bolt having, as usual, a right-hand thread. If the bolt is placed with its head *c* downwards and the nut screwed on the bolt, it will turn towards the right and will at the same time move downwards. The direction in which the nut revolves gives the direction of the lines of force, and the direction in which the nut proceeds indicates the direction of the current. It follows that, should the current be reversed, the lines of force will run in an opposite direction.

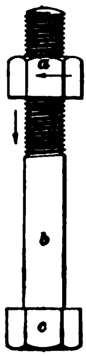


FIG. 22.

40. Attraction and Repulsion of Lines of Force. The rule, given in Art. **10,** stating that lines of force, when

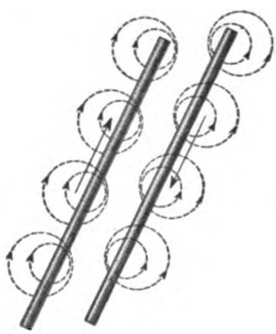


FIG. 23.

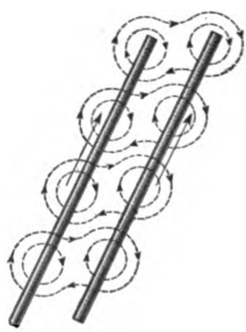


FIG. 24.

running in the same direction, repel one another, and when running in opposite directions attract one another, also holds good for a magnetic field surrounding an active conductor. Let us examine the effect of these attractions and repulsions on two parallel conductors with the currents in them running in opposite directions and placed near each other, as in Fig. 23. Examining the few isolated whirls there represented, we find the lines of force adjoining each other to be running in the same direction; a repulsion will therefore take place. The whirls tend to crowd together near their respective conductors, and as these whirls are supposed to be closely interlinked with the molecules of the conductors, a mutual repulsion of the lines of force will result in a mutual repulsion of the two conductors.

On the other hand, if, as in Fig. 24, the currents in both conductors run in the same direction, the lines of force adjoining each other are found to run in opposite directions; they will therefore mutually attract each other and unite into one line, and as the tendency of each line is to contract itself, the result will be that all the lines of force will seek to draw the conductors closer together; that is, an attraction will take place.

From these experiments we deduct the following law, as first expressed by Ampere:

Rule.—*Two parallel portions of a circuit attract each other if the currents in them are flowing in the same direction, and repel each other if the currents flow in opposite directions.*

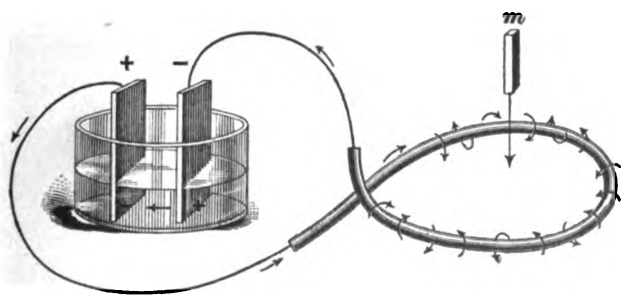


FIG. 25.

If the conductor carrying the current is bent into the form of a loop, as shown in Fig. 25, then all the lines of force around the conductor will pass through the loop in the same direction.

Any magnetic substance, therefore, such as *m*, when placed in front of the loop, would tend to place itself with its longest axis projecting into the loop—that is, in the direction of the lines of force.

41. Solenoid.—It can be easily seen now that by increasing the number of loops, as in Fig. 26, the lines of force of each loop will join into one long loop, enclosing all the conductors, and entering at one end will pass through the whole *helix* to make a return path on the outside. In fact, we find the same conditions that exist in a bar magnet—the lines of force pass out from one end and enter at the other; by closer examination the solenoid is also found to possess a north and a south pole, and will magnetize and attract magnetic bodies. It will also, if freely suspended, place itself in the direction of the magnetic meridian. A helix made in this manner and with a current of electricity flowing through it, is called a **solenoid.**

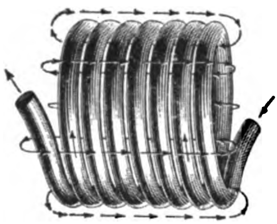


Fig. 26.

42. Direction of Current Around Solenoid.—To determine the direction in which the current will have to circulate around a solenoid, in order to produce a north or a south pole on the end nearest the observer, we may again utilize the rule stated in Art. **39**, giving the direction of the lines of force in an active conductor.

This is purposely done in order to limit the rules requiring memorizing to the fewest possible, and to so connect these rules that they may all be derived from one main rule, if it should occasionally be found necessary to refresh the memory.

In the rule referred to, it was said that the direction of the lines of force around a conductor are in the direction of the hands of a watch, when the current flows away from the observer. If we now reverse the conditions and place the lines of force where the current was, and let the current circulate instead of the lines of force, we have the following modification of the previous rule.

(*a*) **Rule.**—*If the lines of force are flowing into a helix away from the observer, then the direction of the current around the helix will be in the direction of the hands of a watch.*

When the direction in which the current circulates is known, then the rule may be stated in the following form :

(*b*) **Rule.**—*If the direction of the current around a helix is in the direction of the hands of a watch, then the lines of force are flowing into the helix away from the observer.*

We have already seen that in a magnet the lines of force enter at the south pole and leave at the north pole; therefore, when looking at the end of a helix *into* which the lines of force are flowing, we are looking at its south pole. If we are looking at a north pole the current will circulate in a direction *opposite* to that of the hands of a watch.

43. Ampere-Turns.—When the magnetomotive force was mentioned in the previous pages, the source of it was left an open question; it will now be seen that the magnetomotive force depends for its strength on *the intensity of the current and on the number of coils, or complete turns, through which the current passes.* The total number of turns multiplied by the strength of the current in amperes will give the magnetizing force in **ampere-turns.** It has been proven that, for a given number of ampere-turns, it is of no consequence what relation the two factors, amperes and turns, have to each other, so long as their product remains the same. For instance, it is immaterial whether 500 ampere-turns are produced by 100 amperes circulating through 5 turns, or 5 amperes through 100 turns, so long as their product remains 500. *An ampere-turn is defined as the amount of M. M. F. produced by a turn of wire carrying 1 ampere.*

44. Permeability.—It was seen in Art. 28 that, when a magnetic substance is brought into a magnetic field, the lines of force in the field crowd together, and all try to pass through the substance; in fact, they will change their curved shape, as seen in Fig. 16, and go a considerable distance from their original position in order to pass through it. *A magnetic substance, therefore, offers a better path for the lines of force than air or other non-magnetic substances.*

The facility afforded by any substance to the passage through it of lines of force is called *magnetic permeability*, or simply *permeability*.

The permeability of all non-magnetic substances, such as air, copper, wood, etc., is taken as 1, or unity. The permeability of soft iron may be as high as 2,000 times that of air. This is one of the reasons why soft iron is used as a core in the solenoid of the faradic apparatus. If, therefore, a piece of soft iron be inserted into the magnetic circuit of a solenoid, the number of lines of force will be greatly increased, and the iron will be magnetized.

ELECTROMAGNETS.

45. A magnet produced by inserting a magnetic substance in the magnetic circuit of a solenoid is an **electromagnet**, and the magnetic substance around which the electric current circulates is called the **core**, as shown at *C* in Fig. 27. The north and south poles will be as indicated, for reasons already given.

46. Permeability and Conductivity.—It may make matters a little clearer to compare the permeability of a magnetic substance with the conductivity of an electric conductor. With a given electromotive force, the strength of the current in a wire depends on its conductivity. If a wire of less resistance, or higher conductivity, is used, the current-strength will immediately increase in direct proportion to the conductivity. The behavior of a magnetic circuit in a solenoid is somewhat similar. Let a given number of ampere-turns produce a magnetic flux of a certain density; if the resistance of one part of the circuit be decreased by inserting a piece of soft iron in the solenoid, the magnetomotive force will have less resistance to overcome, because the iron is a better magnetic conductor than air and is of a higher magnetic permeability; the result, therefore, will be a corresponding increase in the magnetic flux. It is well to bear in mind that here the similarity ceases, as the permeability is not a constant quantity, like the resistance of a conductor, but varies with the density of the flux.

47. Magnetizing Coil of an Electromagnet.—In an electromagnet, as ordinarily constructed, the magnetizing coil consists of a large number of turns of insulated wire; that is, wire covered with a layer or coating of some non-conducting or insulating material, usually silk or cotton; otherwise, the current would take a shorter and easier circuit from one turn to the adjacent one, or from the first to the last turn, through the iron core, without circulating around the magnet.

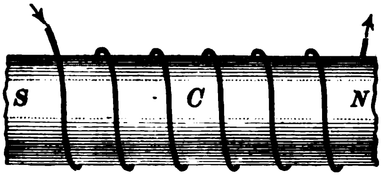


FIG. 27.

An electromagnet in its simplest form is shown in Fig. 27, and as it is usually constructed in Fig. 28. Though the efficiency of an electromagnet in this form is rather low, it has been used to a very large extent in therapeutics as an induction-coil. It consists of a straight bar of iron or steel B fitted into a spool or bobbin $C\,C'$ made of hard vulcanized rubber or some other inflexible insulating material. The magnetizing coil of fine insulated copper wire w is wound in layers on the bobbin, as shown.

48. Polarity of an Electromagnet.—The rule given in Art. 39 determines the polarity of a solenoid when the direction in which the current is flowing is known. The same rule holds good for an electromagnet, and it makes no difference towards which end it is wound, whether wound in one layer or in any number of layers, as long as it is always wound in the same direction around the spool. The main point to observe is that the current shall circulate throughout the coil, always in the *same direction;*

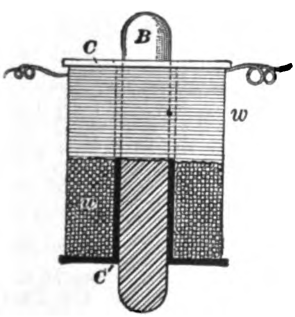


FIG. 28.

as, for instance, in the direction of the hands of a watch. Should the inner layers be wound in a direction opposite to that of the outer layers, there would be a tendency to produce a north pole and a south pole at the same end of the magnet, with the result that the magnetizing forces in each layer would neutralize each other; hence the iron core would not become a magnet.

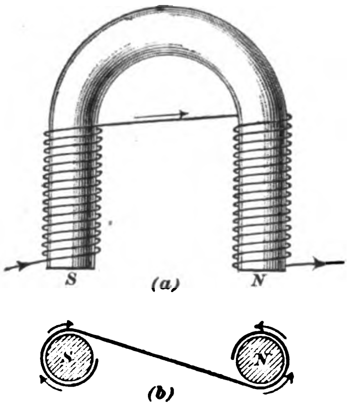


FIG. 29.

49. The Horseshoe Electromagnet.—A form of electromagnet much more efficient than that shown in Fig. 28, and one which is put to a greater variety of uses, is the **horseshoe, or U-shaped,** electromagnet, illustrated in Figs. 29 and 30. It consists of a bar of iron bent into the shape of a horseshoe, with straight ends, and provided with two magnetizing coils, one on each end of the magnet; the two ends, which are surrounded by the magnetizing coils, are the cores of the magnet, and the arc-shaped piece of iron joining them together is known as the **yoke** of the magnet. The ordinary **U**-shaped magnet, shown in Fig. 30, is made in three parts; namely, two iron cores *M* wound with the magnetizing coils *c*, and a straight bar of iron *b* joining the two cores together. In looking at the face of the two cores, Fig. 29 (*b*), and remembering the rule which gave the relation between the polarity and the direction of the current flow, it is seen that the current must circulate in opposite directions around the two cores, otherwise they would both be of the same polarity. If the rules already given have been carefully studied, the

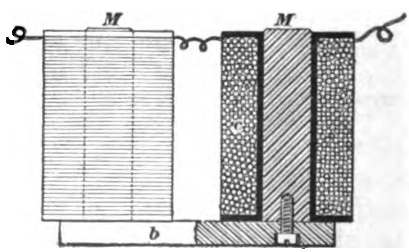


FIG. 30.

reason for winding the two cores of this magnet in opposite directions will be easily understood.

Following the path of the magnetic flux in Figs. 28 and 29 (*a*), it can easily be seen why the latter should be the more efficient of the two. In Fig. 28, the return-path of the lines of force lies along the whole length of the bar *B*, and, being through air, must necessarily be of high resistance. In Fig. 29 (*a*), the lines of force have simply to cross over the gap between *N* and *S*, while the rest of the circuit is completed through iron. Bringing the poles closer together would decrease the resistance still more.

50. The Iron-Clad Electromagnet. The electromagnet of the least resistance is the one known as the **iron-clad electromagnet,** and illustrated in Fig. 31. It contains only one magnetizing coil and one core. The core *M* is fastened to a disk-shaped yoke and the magnetic circuit is completed through an iron shell *S* that rises up from the yoke and completely surrounds and protects the coil. If an armature is placed in front of the core, the paths of all the lines of force will be through iron.

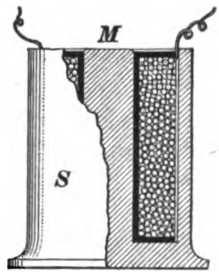


FIG. 31.

ELECTROMAGNETIC INDUCTION.

51. Electromotive Force in a Conductor.—It has been shown that a magnet is constantly surrounded by a field of magnetic force, and also that the surrounding space of a conductor is immediately filled with circulating lines of force, as soon as a current begins to pass through it. Further on it was shown that the lines of force surrounding two or more magnets or two or more conductors react on each other; that is to say, not alone magnet on magnet, but also magnet on conductor. On observing the phenomenon that lines of force begin to move around a conductor on the closing of the circuit, the question might perhaps suggest itself as to whether a reversal of the phenomenon was possible; or, in other words, whether lines of force could be made to create an electromotive force in a conductor and start a current. Faraday made the important discovery that this effect is indeed produced in a conductor under the conditions mentioned, and thus laid the foundation of the principles on which the dynamo of today is based.

In the following pages we will therefore consider the other methods mentioned in Art. **21**, *Direct Currents*—those producing an E. M. F. by means of dynamo-electric machines, induction-coils, etc. In either of these appliances it is a question of interaction between magnetic lines of force and electric conductors and of producing a motion of the lines of force or of the conductors, as the case may be.

52. This interaction between magnetic lines of force and a conductor can be shown by means of the following apparatus: In Fig. 32 (*a*), *a* is a solenoid, whose terminal wires *c* and *d* are wound a number of times around the compass *e*, which then serves as a *galvanometer*, an instrument described in *Essential Apparatus*. From the explanation given in Art. **36**, it is clear that if a current is passing through the wires *c* and *d* it will affect the compass and compel it to swing either to the left or right, depending on the direction of the current. If, now, the magnet *b* is moved quickly into the interior of the solenoid, the compass needle will swing through a certain angle, proving that a current has been passing through the solenoid. As soon as the magnet stops its motion, the needle will swing back to its initial position and come to rest.

When, now, the magnet is withdrawn from the solenoid, the needle will again swing through a certain angle, but in an opposite direction to that of its first deviation, proving that in this instance again a current was started, but in an opposite direction to the former current.

It will also be found that no current is flowing so long as the magnet remains stationary, but only when a change takes place in the position of the magnet. The quicker these motions are, the more will the needle deviate, and, consequently, the stronger the actuating current must have been. Of course, the same effects will be produced if the magnet is stationary and the coil constitutes the moving part.

53. A Solenoid Conveying a Current Acting as a Magnet.—On replacing the magnet by another solenoid *b*, as in Fig. 32 (*c*), the results will be similar; on letting *b* enter the solenoid *a*, a current will flow through the latter in an opposite direction to that of the other current, which is established by the removal of the solenoid *b*.

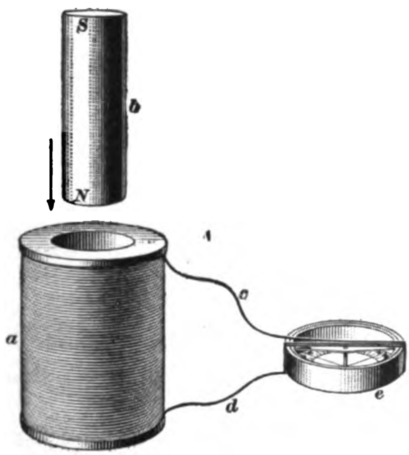


Fig. 32 (*a*).

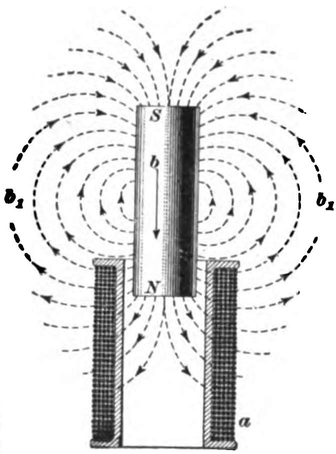


Fig. 32 (*b*).

It is further found that if this solenoid conveying a current is placed inside another solenoid, and the circuit of the former *broken*, a current will flow in this latter solenoid as if the solenoid conveying a current had been suddenly withdrawn. Likewise is it found that on again *closing* the circuit the effect on the solenoid not conveying a current will be the same as if the solenoid conveying a current had been reinserted. In fact, any weakening or strengthening of the current in the solenoid conveying a current has the same effect as if the coil was approaching or receding from the solenoid conveying no current.

We see, then, that a current is flowing through the coil *a* *only* when one of the coils moves relatively to the other, or when the strength of the current in the active coil is changing. As long as both coils remain stationary, or the current in the active coil does not vary in strength, *no* current will flow in the coil in which a current is to be induced.

That, in these experiments, the magnet *b* and the active coil *b* both have the same effects on the coil in which a current is to be induced should not be surprising, as it was shown in Art. **41**, and by means of Fig. 26, that a solenoid possesses

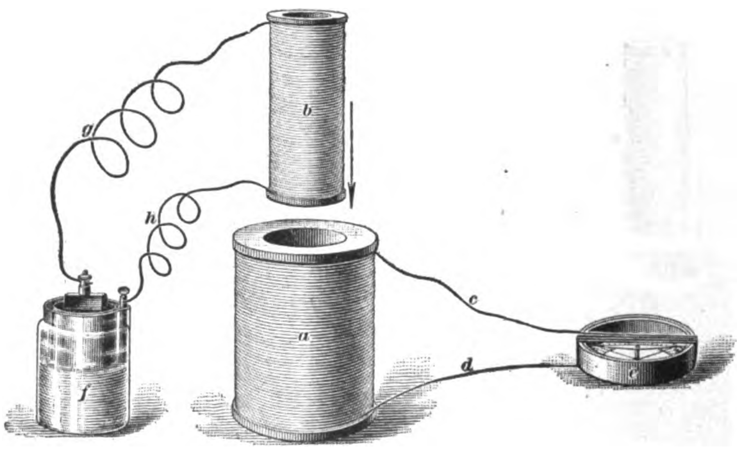


FIG. 32 (*c*).

lines of force which flow through and around it in the same manner as those of a permanent magnet.

In looking for an explanation of these phenomena we will have to investigate the actions of magnetic lines of force on a conductor, when the latter is in motion relative to the former.

In Fig. 32 (*b*), the coil *a* in which we wish to induce a current is shown in cross-section, and the magnet *b* is surrounded by dotted lines b_1, indicating the position and direction of its magnetic lines of force. We see these lines of force pass through the surrounding copper wires without being diverted from their course, and as if these wires did not exist. If, now, the magnet is moved downwards, these lines of force will pass across the various turns of wire in the coils, and a certain interaction between the conductor and the lines of force will take place, whereby an electromotive force is created in the coil. There will then be a tendency to start a current, and if the circuit is closed, as in Figs. 32 (*a*) and (*c*), a current will flow in the coil and show its presence by its action on the compass *e*.

54. Direction of Induced E. M. F.—We will now have to consider this interaction between a conductor and lines of force more in detail and find some rule that will indicate in which direction the induced E. M. F. tends to act, when the lines of force are flowing in a given direction.

The principle according to which this interaction takes place may be stated as follows: *A conductor, moving across a magnetic field so as to cut the lines of force, will have an electromotive force produced in it, and the direction of this E. M. F. in the conductor will depend on the relative directions of the magnetic flux and the motion of the conductor.*

Fig. 33 will make this principle clearer. The lines of force are here passing from the north pole *N* of a horseshoe magnet, and through the air-gap in the direction indicated, to the south pole *S*. The conductor *A*, shown in cross-section, is moving across the field in the direction of the arrow, and an electromotive force will now be produced in the conductor, which tends to send a current through the same downwards, through the paper. It is seen that the current will then flow in a direction at right angles to the direction of the lines of force and also to the direction of motion. If the motion of *A* is reversed, the current will pass upwards away from the paper.

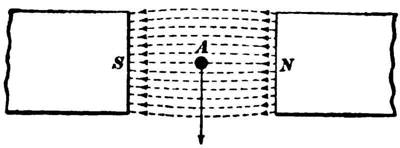


FIG. 33.

It is important that this principle be well understood, as by its means all phenomena connected with electricity in motion can be easily explained and analyzed in all their variations. Many rules have been suggested by means of which to make the direction of the induced currents more easy to remember. The one suggested by Dr. Fleming is as follows :

Rule.—*Hold the thumb and the first and the middle finger of the right hand as nearly as possible at right angles to each other, as in Fig. 34, so as to represent three rectangular axes in space. If the thumb points in the direction of the motion, and the forefinger along the direction of the magnetic lines, then the middle finger will point in the direction of the induced electromotive force.*

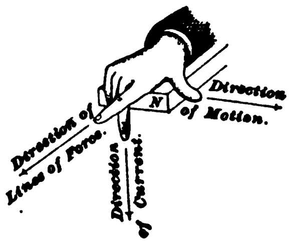


FIG. 34.

Also, the following adaptation of Ampere's well-known rule is frequently used.

Rule.—*Imagine a swimmer to be floating along a conductor and that his face is turned in the direction in which the lines of force are moving. If both the swimmer and the conductor are moved towards his right hand, the direction of the electromotive force induced by this motion will be from the feet to the head of the swimmer.*

55. The following rule has been found very easy of application:

Rule.—*Imagine a triangle B, Fig. 35 (a), placed on a table with its high side to the right, and let a pencil A be held against its upper edge. Suppose, now, that the lines of force are passing from the observer's eyes and proceeding towards the triangle, and that the pencil be moved to the left. When it reaches the point of the triangle, it will, in addition to its lateral motion, also have made a downward motion, indicating that the electromotive force produced in the conductor tends to send a current in a downward direction. By moving the conductor towards the right, the reverse will take place; i. e., the current will tend to flow upwards.*

After this explanation, Fig. 35 (*b*) alone will be sufficient to determine the direction of the induced electromotive force by merely imagining the lines of force to proceed from the observer's eyes towards the paper, so that when the pencil moves in the direction indicated, the direction of the induced electromotive force will be towards the bottom of the page.

It is well to call attention to the fact that in the rule just given, no mention has been made of a current flowing; it has simply been said that the electromotive force tends to act in a certain direction, and that it will continue to act so as long as

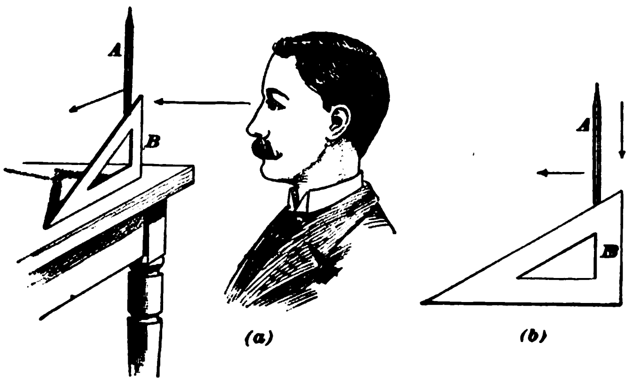


FIG. 35.

the conductor continues to cut across the lines of force. Whether or not a current will flow depends upon the condition of the circuit. If the circuit is closed a current will flow; if it is open no current will flow.

56. Magnitude of the E. M. F.—The **magnitude** of this E. M. F. will depend not only upon the number of lines of force cut through, but also upon the rate at which they are cut. If the conductor passes very rapidly through the magnetic field, the E. M. F. will be very high, but not of long duration, while a slow passage through the field will produce a weak E. M. F., but one sustained correspondingly longer.

57. Absolute Unit of Potential.—*One absolute unit of potential* is the potential produced in a conductor when it is cutting lines of force at the rate of *one line of force per second.*

By definition, *1 volt* is equal to 100,000,000, or 10^8, absolute units; consequently, in order to produce an electromotive force of 1 volt, the rate of cutting must be 10^8 lines of force per second. This can also be expressed algebraically; thus,

$$E = \frac{N}{10^8 \times t},$$

where E = electromotive force in volts;
N = total number of lines of force cut by the conductor;
t = time in seconds taken to cut the lines of force.

If the total number of lines of force remains unchanged, it will make no difference in the electromotive force developed, whether the lines of force proceed from a permanent magnet or from an electromagnet.

58. Cutting Lines of Force.—According to Ohm's law, the current obtained from conductors cutting lines of force is equal to the quotient arising from dividing the total electromotive force generated by the total resistance of the circuit through which the current passes. In general, the total resistance is the resistance of the conductor cutting the lines of force, or the resistance of the *internal* circuit, plus the resistance of any conductor or conductors that complete the *external* circuit. If E represents the total electromotive force in volts, r and R the resistance in ohms of the internal and external circuits, respectively, and C the current in amperes, then $C = \frac{E}{R + r}$.

59. Limit of Induced E. M. F.—It will be seen from the above expression that either a large or a small induced current can be obtained from conductors cutting lines of force by simply changing the combined resistance of the internal and external circuits. There is, however, a maximum limit to the amount of current obtainable in this manner. The lines of force, which are produced around the conductor by the current itself, will always act in opposition to those producing the electromotive force, and will tend to distort or crowd them away from their original direction. The number of lines of force produced around the conductor by the current, is directly proportional to the strength of the current, and consequently, as the current becomes larger and larger, the lines of force which are being cut by the conductor become more and more distorted and crowded away from their original direction, until the conductor is no longer able to cut all the lines of force, and therefore the generated electromotive force becomes smaller. A means generally employed to get rid of this effect is to make the density of the magnetic field large in proportion to the current. This interaction between the lines of force around the conductor and the lines of force cutting the conductor also explains why it becomes more and more difficult to move a conductor through a field as the field grows stronger, as in a large dynamo, and why it requires hundreds of horsepowers to turn an armature, which, when the dynamo is at rest, may be turned by hand.

Fig. 36 shows that the direction of the lines of force on the front of the moving conductor is such that a mutual repulsion will take place between them and the lines of force of the stationary field, tending to push the conductor in a direction contrary to the one in which it is moving; while, on the other hand, the lines of force on the rear of the conductor exert an attraction on the cutting lines of force, and seek, like the lines in front, to prevent the motion of the conductor. This reaction may be compared with the resistance which the air exerts on an oscillating fan; an increase in speed will be met with an increased resistance; while on the cessation of motion the resistance will vanish altogether.

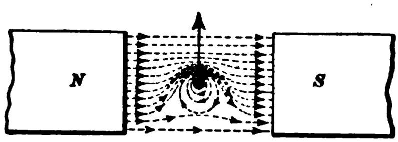


FIG. 36.

60. Stationary Conductors and Moving Fields.—It must not be supposed that, in order to produce an electromotive force in a conductor, it is necessary for the latter to move, and that the magnetic field must always remain stationary; on the contrary, the fact is that the opposite case, that of the stationary conductor and a moving field, is a combination as frequently met with in regular practice. The millions of telephones in use are examples of stationary conductors and moving fields, and, to quote a few other instances, so are the transformers and induction-coils. It makes no difference which one of the two elements is in motion so long as the cutting of lines of force takes place. It is no matter whether both are moving in opposite directions or whether both are moving in the same direction with a different speed, with the result that there is a relative motion between them. The rule illustrated by Fig. 35 holds good in either case; it is only a question of determining the direction of the relative motion between the two elements; but should it be desirable to apply the rule directly to the case of a moving field and a stationary conductor, then simply move the triangle in the direction of the moving field, while the pencil is allowed an up-and-down motion only. The direction in which it is moving will then be an indication of the direction in which the electromotive force is acting.

VARIOUS MEANS FOR INDUCING AN E. M. F.

61. Classes of Induction.—All these various combinations of moving magnetic fields and conductors are usually classed under the following four headings: magneto-electric induction; electromagnetic induction; mutual induction; self-induction.

It would perhaps have been more correct to place the self-induction and mutual induction first, but as these subjects are more easily comprehended when an explanation has been given of the magneto-electric induction, they have been arranged in the above order.

62. Magneto-Electric Induction.—In magneto-electric induction, an electromotive force is induced in a conductor by moving it across a magnetic field or by passing a magnetic field near a conductor; it is immaterial which is done so long as a relative motion between the conductor and the magnetic field takes place. It has already been described, in Art. 52, how the cutting of lines of force affects a conductor and the direction in which the E. M. F. is acting; it now remains to show the application of the law. In Fig. 37, *A* is a permanent magnet with its north pole at *N* and its lines of force proceeding in the direction of the arrows; *C* is a coiled conductor shown in cross-section, that portion of the coil which is cut away being indicated by dotted lines. If the magnet is moved towards and into the coil in the direction indicated by the arrows, the conductor will cut lines of force, and an E. M. F. will be produced in the coil. Let us, by means of Fig. 35 (*b*), try to determine the direction in which this E. M. F. is acting. Considering only that portion of the coil marked *B*, and looking at it in the direction of the lines of force, we see that the lines of force are moving towards the left-hand side of the coil. Therefore, moving the triangle in Fig. 35 (*b*) also to the left, it is observed that the pencil moves upwards; the E. M. F. in the part *B* is therefore also acting in an upward direction. Looking into the coil from the end where the magnet enters, the current will circulate in the coil in a counter-clockwise direction, and the right-hand end of the coil must be a north pole. As it is known that similar poles of magnets repel each other, the coil will tend to prevent the entrance of the magnet. If, on the contrary, the magnet is moving out of the coil, the direction of the current will be reversed and the right-hand end of the coil will then be a south pole; consequently, an attraction will take place between magnet and coil; hence, the latter is seeking to prevent the removal of the magnet. These effects take place *only* when the magnet is in *motion;* as soon as the motion ceases the current stops. We have here a confirmation of the experiment illustrated by means of Fig. 32 (*a*). Upon this action of a magnet on a coil, the following rule, called **Lenz's law,** has been based.

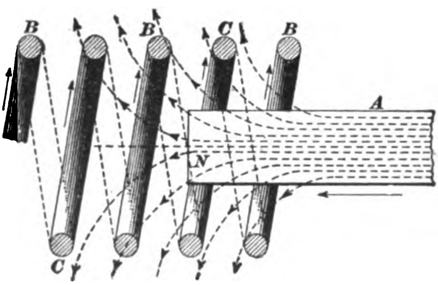


FIG. 37.

Rule.—*When a conductor is moving in a magnetic field a current is induced in the conductor in such a direction as by its mechanical action to oppose the motion.*

63. Electromagnetic Induction.—In electromagnetic induction, the magnetic field is produced by an electromagnet instead of a permanent magnet, as shown in Fig. 32 (*c*); otherwise the conditions are the same. This combination is illustrated in Fig. 38, in which *A* again is the moving magnet (here a solenoid) in which the current circulates in the direction indicated by the arrows. The stationary coil *C* is here shown in cross-section with the upper part indicated by dotted lines. The cutting of lines of force will affect the parts *B* in the same manner as before, and the current in the parts marked *B* will therefore be in the direction of the arrows. Comparing the direction of the currents in the two coils, it will at once be seen that they are flowing in *opposite* directions, and, from the previous experiment, we will come to the conclusion that when *A* is retreating, they will move in the *same* direction. As it has already been demonstrated that parallel conductors repel each other when their currents run in opposite directions, and attract each other when they run in the same direction, it can at once be seen that the coil *C* opposes both the advance and retreat of the coil *A*. The magnetic flux started by the coil *C* is in a direction entirely opposed to that of the coil *A*, and its tendency is to diminish the flow of the latter, and therefore also to diminish the strength of the current in the coil *A*. Applying Lenz's law to this phenomenon, we may sum up the matter by saying that *in all cases of electromagnetic induction the induced currents have such a direction that their reaction tends to stop the motion which produces them.*

64. Mutual Induction.—The mutual induction is in reality only a modification of the electro-magnetic induction. We observed before that it was immaterial whether the conductor or the magnetic field was moving, so long as the lines of force were cut by the conductor. We may therefore go a step further and imagine the coils in Fig. 38 as stationary, and by some means impart a motion to the magnetic field; a current should then be started in the coil *C*. The only question would be how to move the magnetic field of the coil *A* without moving the coil itself.

Art. 38 stated that an increase in current-strength was followed by an increased number of lines of force encircling the conductor, and also by a spreading of the same; that is to say, the magnetic whirls could be supposed to increase their diameters. Illustrating these motions more fully by means of Fig. 39, we may imagine a current of a certain strength to be flowing through the coil *A*, and that the lines of force *a*, *a*, *a* are produced by the same. If, now, the voltage and strength of the current were increased, the lines of force would move forward to the left until they occupied the position of lines *a'*, *a'*, *a'*. This motion would be equivalent to a motion of the whole coil *A*, and would be accompanied by the same result—that is, the starting of a current in an opposite direction. The tendency of the induced current will be to again send an opposing magnetic flux through the inducing coil and thus diminish the flow of both magnetism and electricity. As long as the strength of the current in the coil *A* is constant, the lines of force circulating around it will remain in the same position, and there will be no current in the coil *C*; it is only while changing their positions that forces tending to counteract these changes begin to work. A decrease or stoppage of the current in coil *A* is followed by a retreat or a complete collapse of its lines of

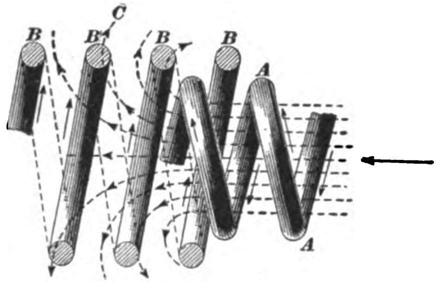


FIG. 38.

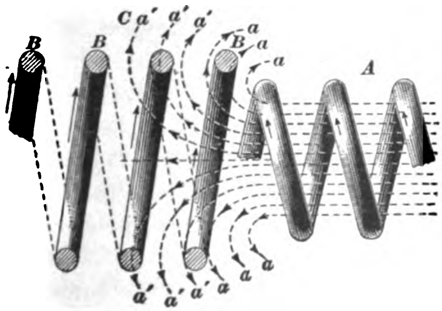


FIG. 39.

force; and, as the latter now have to move across the conductor *B* in an opposite direction, the induced current will also have changed its direction to one corresponding with that of the inducing current. As a consequence of this, the induced current tends to start a magnetic flux in the same direction as that of the coil *A*, striving to keep up its flow and prevent its decrease and stoppage. *A* is usually called a *primary* and *C* a *secondary* coil.

65. Self-Induction.—The phenomenon of self-induction may be considered as a case of mutual induction. Let Fig. 40 represent a combination of five conductors projecting through the paper; when a current is sent through the conductor *A* in a downward direction, the lines of force *a* will circulate in a direction indicated by the arrows. As long as the current-strength remains constant no effect is noticeable in the conductors *B*, but an increase in its strength will immediately be

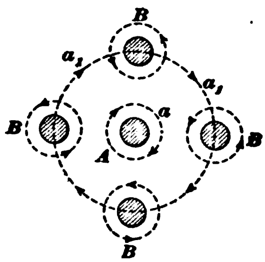


FIG. 40.

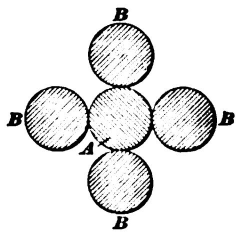


FIG. 41.

followed by a spreading of the lines of force into a position a_1, and a cutting of the latter by the conductor *B*. The result will then be the creation of electromotive forces in the latter which will send a current upwards, and, therefore, in a direction contrary to that of the current in conductor *A*. A stoppage of the inducing current will of course be the cause of reversing the currents in conductor *B* so that they now will flow in the same direction as that of *A*. Let us now apply these results to an explanation of self-induction, by placing all the conductors in contact with one another; therefore, in reality, constructing one large conductor out of several smaller ones. Fig. 41 represents such a combination. Of course it is at once seen that sending a current through A only will again be accompanied by results corresponding to those indicated in Fig. 40; but, in the present instance, we have to imagine that the conductors B also are carrying a current, and that all of the conductors are subjected to mutual induction. The effect will be that every conductor will tend to stop the current flow in the surrounding conductors. On the other hand, when the current is decreasing or stopping, all the returning lines of force of each conductor will have a tendency to maintain the current in its neighbors. It is not necessary that a conductor should be made up of several independent conductors in order to be under the influence of self-induction. On the contrary, we can imagine any solid conductor to be made up of numerous smaller ones, all influencing one another in the manner just described. We must therefore come to the following conclusions: *That any conductor tends to oppose the passage of a current through it by setting up an electromotive force acting in opposition to that of the current; and further, that after a current is flowing, the conductor tends not alone to prevent an increase, but also a decrease of same.* This opposing E. M. F. is also called a **counter-electromotive force.**

66. Extra Current.—A decrease or stoppage of the current is, as previously shown, accompanied by a vanishing of the lines of force from the space surrounding the conductor; the lines of force belonging to the various parts of the conductor will therefore tend to maintain the current and will prevent a sudden decrease or stoppage of the latter. These induction effects are called **self-induction**; they are always present whenever a current begins to flow in a circuit, also when its strength varies and when it stops. As soon as the circuit is closed, the current should at once attain its full strength; but it does not. Some little time is required, during which the magnetic flux around the conductor is constantly increasing in strength. We have seen that the cause of this is the setting up of an electromotive force, called counter-electromotive force, because it is acting in opposition to the impressed electromotive force. Again, it is noticed that when a circuit is suddenly broken, there appears a minute spark at the point of opening. This is because the self-induction of the circuit at this moment is very great, the lines of force closing up with great rapidity, and therefore a high induced E. M. F. is generated in the same direction as the impressed E. M. F., thus causing a strong current to flow. This current is called an **extra current.** This extra current is always produced when the circuit is broken. In a straight conductor its effects are not so noticeable; but if the conductor be formed into a coil, and provided with an iron core, then, on opening the circuit, there will be a brilliant spark, and a person holding the two ends of the wires between which the circuit is broken, may receive a slight shock, owing to the high E. M. F. of this self-induced or extra current.

67. In the previous explanation of induction, the action of the lines of force has been gone into in some detail, as otherwise the phenomena could not very well be understood. Ordinarily, such a detailed examination will not be necessary, although it is well to be in possession of the means required for such investigations. When it comes to the action of a magnet entering a coil, or the mutual induction of two coils in proximity to each other, it is sufficient to remember the rule given in Art. **63**, that a conductor moving in a magnetic field has a current circulating in it in such a direction that its mechanical action will tend to oppose its motion. It is necessary, however, to be perfectly sure of the direction in which the current circulates around a north and south pole, and in which direction the lines of force are flowing in a magnet.

It may be well to give a few practical examples of the various means employed for producing an induced electromotive force, such as the *sinusoidal alternator*, the *induction coil*, and the *transformer.*

THE SINUSOIDAL ALTERNATOR.

68. Elementary Principles.—It has been explained how an E. M. F. is produced in a conductor moving in a magnetic field and rules have been given for determining the direction in which this E. M. F. will act; there should, therefore, be little difficulty in finding the direction of the E. M. F. produced in the elementary apparatus shown in the following pages.

In Fig. 42 (*a*), let *N* represent the north pole of a permanent magnet and *l l* the lines of force emanating from the same in the direction indicated. The conductor *C* is moving downwards in front of the pole, thereby cutting the lines of force. From the rules given in Arts. **54** and **55**, it is seen that the E. M. F. produced in the conductor *C* will act in the direction of the arrow *a*, thereby making the end *p* positive and *n* negative. As a means for producing an E. M. F., this arrangement would not be very suitable and some provisions should be made whereby the motion of the conductor *C* could be made continuous. An arrangement of this kind is indicated in Fig. 42 (*b*), where the conductor *C* has been bent into a form that will allow the ends *p* and *n* to revolve in the bearings $B\ B_1$ that support them, while the part *C* revolves along the path indicated by the circle *A* in the direction of the arrow *c*. In this manner, it will be possible by any suitable means to set the conductor *C* in rapid rotation, the rapidity of this rotation determining the strength of the E. M. F. produced, the latter acting in the direction of the arrow *a*.

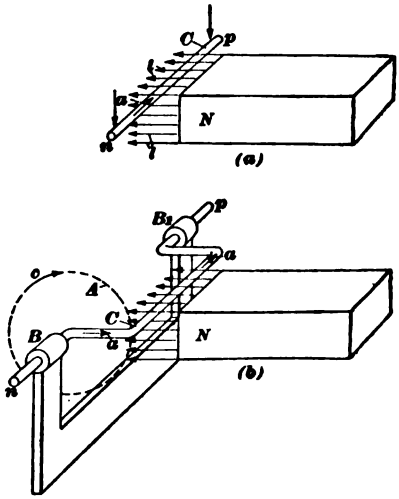


FIG. 42.

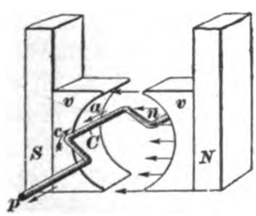


FIG. 43.

As the magnetic field in both of these examples is that of a bar magnet, it is not the one best suited for our purpose because the lines of force will be too much dispersed. To overcome this we have in Fig. 43 made use of a horseshoe magnet, N and S representing the ends of one to which pole-pieces v, v of soft iron have been attached; the latter have their interior sides concave in order to conform with the path of the revolving conductor C, thereby submitting the latter to a magnetic field of much greater intensity.

When the conductor C revolves in the direction indicated by the arrow c, the E. M. F. produced will tend to act in the direction of arrow a and the end p will be positive, and n negative. The E. M. F. will continue to act in that direction until the conductor C reaches its lower position and begins to act in an upward direction. Then it cuts the lines of force in the opposite direction and consequently the resulting E. M. F. will also change. We see, then, that for each half of a revolution the E. M. F. will be reversed in direction. While C rotates in the left side of the magnetic field and moves upwards, p will be positive; but when it moves downwards in the right half of the field, p will be negative. So far the E. M. F. produced has had no opportunity to start an electric current, because the conductor C does not constitute part of a closed circuit. By the arrangement shown in Fig. 44 (a), a closed circuit is provided by placing two disks p_1 and n_1 at the ends p and n. Against these disks press springs m_1 and m_2, which are connected with each other by means of the conductor R. The E. M. F. acting on C will now start a current through this circuit in the direction of the arrows. Fig. 44 (b) indicates the change in the conditions when C moves downwards. The current is now flowing in the opposite direction. In either case the arrows l indicate the lines of force proceeding from the north pole of the magnet.

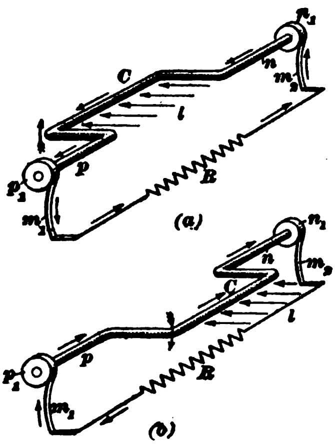


FIG. 44.

By means of Fig. 45 (a) and (b), a graphical representation is given of the extent and direction of the E. M. F. in the various positions the conductor C may occupy with special reference to the E. M. F. the disk p_1 may be in possession of. In Fig. 45 (a), the small circles C_0, C_1, C_2, C_3 indicate four main positions that C occupies during a complete revolution. In Fig. 45 (b), the values of the E. M. F.'s produced while passing through these positions are indicated. When C occupies the lowest position C_0 it cuts no lines of force, because running

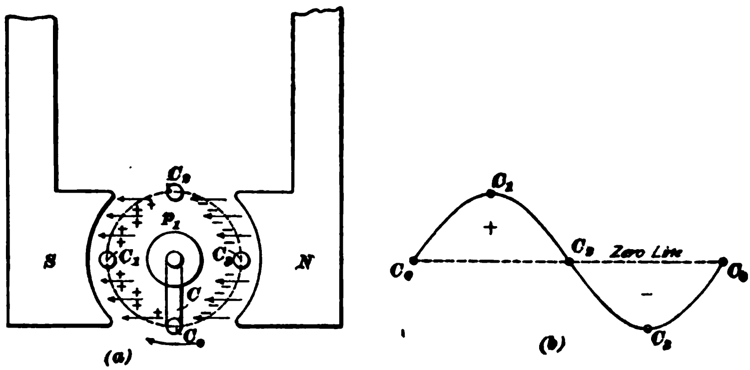


FIG. 45.

parallel with them, and no E. M. F. is produced. In the curve, Fig. 45 (b), C_0 is therefore placed on the zero lines. When C passes through the position C_1, it cuts the lines of force at the maximum rate and will be in possession of a maximum E. M. F., which will be positive, as illustrated in Fig. 44 (a). The curve, Fig. 45 (b), shows C_1 at the top of the curve and above the zero line, because positive. When the position C_2 is reached, the conductor again cuts no lines of force and is in possession of a zero E. M. F., and C_2 will also be on the zero line of the curve. When the conductor C passes to the right of the point C_2, the E. M. F. changes direction and p_1 [see Fig. 44 (b)] will be negative. At C_3, the conductor has reached its maximun negative potential, as indicated at the point C_3 of the curve. From here on, the E. M. F. again rises to the zero point C_0 corresponding to the point at which the revolution began.

From the descriptions given in *Direct Currents*, we see at once that the curve represents an alternating E. M. F.; whether this curve will be a true sine curve or not depends on the construction of the pole-pieces *v*, *v*, Fig. 43.

69. Action in a Rotating Coil.—So far we have explained a most elementary apparatus, unsuited for practical purposes mainly because the E. M. F. produced will be very small. The reason for this is that only one conductor is cutting lines of force and only one side of the magnetic field is used at a time. If we bend the conductor into the shape indicated in Fig. 46, it will constitute a closed coil of rectangular form, and the increased number of convolutions will increase the number of conductors

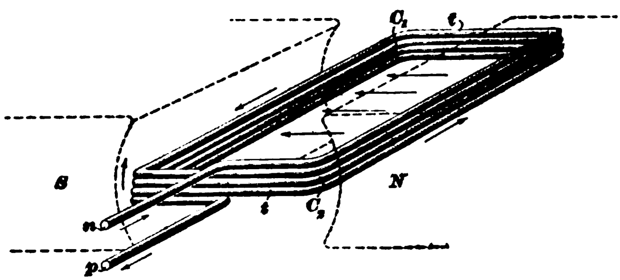


FIG. 46.

simultaneously cutting lines of force with a corresponding increase in the E. M. F. produced.

An examination of Fig. 46 will show that while the conductors C_1 constituting one side of the coil, moves upwards, the other side, made up of conductors C_2, moves downward. They will, therefore, cut the lines of force in opposite directions, with the result that the E. M. F.'s produced in the conductors will act in opposite directions. For instance, the E. M. F.'s in the conductors C_1 seek to send a current toward the front, while the conductors C_2, on the contrary, send one to the rear. But on tracing the path of the E. M. F.'s through the various convolutions, we see that all the E. M. F.'s act in the same direction with reference to the coil itself. The result is that, for this position of the coil, the terminal marked *p* will be positive and the terminal *n* negative.

In order to explain the increased E. M. F. resulting from the increased number of conductors, we will suppose that each of the conductors C_1 has an E. M. F. produced in them, while passing in front of the pole S, amounting to $\frac{1}{10}$ volt; the same applies to the conductors C_2 while passing in front of pole N. If we now trace the path of the current through the various convolutions, beginning at terminal n, we arrive first at the uppermost of the C_2 conductors, where the current receives its first electromotive impulse of $\frac{1}{10}$ volt; the current then proceeds through the transverse part t over to the first of the C_1 conductors, where it again receives an increase in pressure of $\frac{1}{10}$ volt, and so forth. Each one of the conductors C_1 and C_2 increases the pressure of the current to the amount of $\frac{1}{10}$ volt, until the current finally reaches the terminal p with a pressure amounting to the sum of all the pressures given by the individual conductors. For instance, if the coil were made up of 200 convolutions, the conductors C_1 and C_2 would each constitute 200 separate conductors, in all 400, that would simultaneously cut lines of magnetic force. The result would be that a total E. M. F. of $400 \times \frac{1}{10}$, or 40 volts would be produced. When the conductors C_1 have reached the position now occupied by C_2, they will have undergone a change in the direction of the E. M. F. to which they are subjected, as it necessarily will be the same as that now acting on C_2. The same will take place in C_2 when coming in front of the pole S and the terminals p and n will change polarity, as already shown by means of Figs. 44 (a) and (b).

In order to shorten the air-gap between the pole-pieces N S, Figs. 43, 45 (a), and 46, it is customary to fill as much as possible of this space with iron, whereby a more intense field is provided for the conductors. The iron cylinder I, Fig. 47, not only serves this purpose but also that of supporting the coil C; for this reason the cylinder or core I has grooves K, K along which the coil is wound. The core and coil together constitute an **armature.** A shaft R R supported in suitable bearings provides a means for setting it in rotation.

The terminals p and n are connected to the two rings p^1 and n^1, from whence the current may be led by means of the two springs r^1 and r^2, Fig. 48, to any conductors that may be attached to them. These rings p^1 and n^1 are insulated as well from each other as from the shaft. In Fig. 48, which represents a complete sinusoidal alternator, *M*, *M* are the two permanent

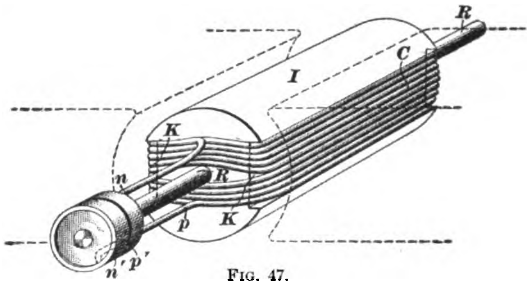


FIG. 47.

horseshoe magnets, the lower parts of which are surrounded by the box *V*, which conceals the pole-pieces and armature and contains the bearings *b*, *b*. *H* is a pulley by means of which the armature may be set in rotation, the power being supplied from any suitable source.

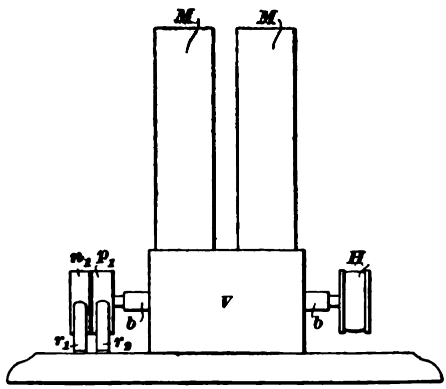


FIG. 48.

70. The Undulating Current.—In place of the sinusoidal alternating E. M. F. represented by means of Fig. 45 (*b*), it is often of advantage to produce an E. M. F. that is unidirectional, but still in possession of a wavy character. For instance, if the negative wave C_2, C_3, C_0, Fig. 45 (*b*), were turned up so as to make it positive, we would have a curve, represented in Fig. 49, consisting of two successive positive waves with the zero points C_0, C_2, C_0.

Some of the modern sinusoidal apparatus are able to furnish this unidirectional wave current in the following manner:

Instead of the two rings shown in Fig. 47, two segments S_1 and S_2, Fig. 50, are used; each is provided with a tongue t_1 and t_2, which overlap each other when in position on the shaft *R*, Fig. 51 (*a*). These segments are also insulated from each other and from the shaft. The two segments are connected to their

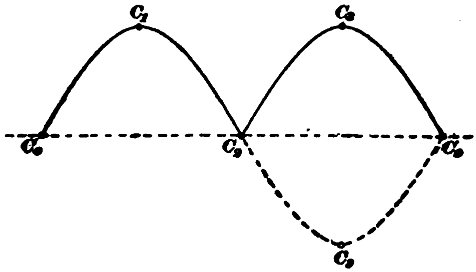


FIG. 49.

respective terminals *p* and *n*, as shown in Fig. 51 (*a*), and four springs *1*, *2*, *3*, *4* rest against the segments for the purpose of conducting the current away to the various circuits. In this arrangement, the springs *1* and *2* and those parts of the segments against which they rest will perform the same function as the springs r_1, r_2 with rings n_1, p_1 in Fig. 48. That is, S_1 and S_2 will successively change from positive to negative after each half-revolution. With the springs *3*, *4* and the tongues t_1, t_2, the conditions are different. In the position indicated by Fig. 51 (*a*), S_1 is positive and S_2 negative, and as the spring *4* rests against t_1, a continuation of S_1, it must also be positive and, similarly, *3* negative. In Fig. 51 (*b*), S_1 has changed into such a position that the grooves that separate the two segments are in line with the springs.

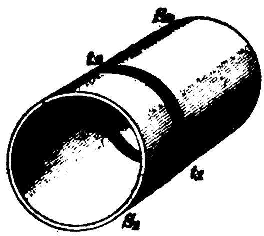


FIG. 50.

This is better shown in Fig. 51 (*d*), which represents a cross-section through the segments, and the springs *3*, *4* resting on the insulating material that separates them. In this position, the coil occupies the position C_0 and C_2, Fig. 45 (*a*), and has, therefore, no E. M. F. produced in it. This is also the position where the segments S_1, S_2 change polarity and in which position the springs are not in contact with them. In Fig. 51 (*c*), the segments have changed places; S_1 is now negative and S_2 positive, but spring *4* is now resting on S_2 and is positive as before, while S_1 is negative. In the circuit *P* connected with the binding-posts *3*, *4*, we find that the current is constantly flowing in the same direction, but it is not constant. It has the wavy nature, represented by the

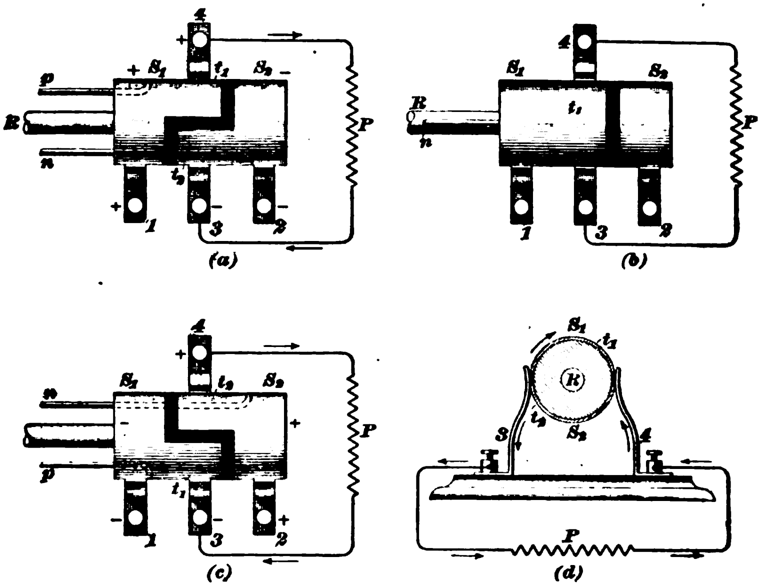


FIG. 51.

curve, Fig. 49, because the coil, twice during each revolution, passes through a region where it cuts no lines of force and therefore has no E. M. F. produced. When these segments S_1, S_2 are so constructed that the springs *3* and *4* receive a direct current, they constitute a device called a **commutator,** because they commute currents running in different directions into such that run in the same direction.

71. A Typical Sinusoidal Alternator.—A a rule, these sinusoidal alternators are driven by a small direct-current motor, as seen in Fig. 52. The shaft of this motor is coupled directly to that of the alternator and the speed of the alternator may be changed by changing that of the motor. This is effected by means of the rheostat to the left, which is connected with the direct-current circuit. The current from the sinusoidal alternator is led to the two small binding-posts in front, which may be connected to the patient's circuit; the rheostat to the right regulates the current strength in the latter. The double lever seen in the center of the base is for the purpose of selecting either the sinusoidal or the unidirectional current.

The full explanations that have been given of the action of the lines of magnetic force on a conductor cutting through them

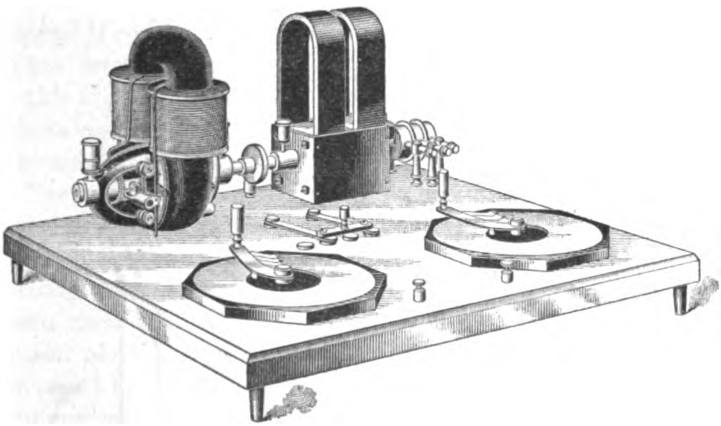


FIG. 52.

will greatly help the student to understand the action of a dynamo or motor when such apparatus is considered further on.

72. The Kennelly Sinusoidal Alternator.—A peculiar form of alternator is the *sinusoidal alternator*, constructed by A. E. Kennelly; it is intended to furnish sinusoidal alternating currents, and is shown in Fig. 53. Here *A*, *A* are spools with two separate coils, an inner one with eight layers of fine wire and an outer one with two layers of coarse wire.

The inner coils are all connected in series and constitute the secondary coil, while the outer coils are connected in another series and form the primary coil of the machine. The primary coils are connected with the binding-posts *P*, *P*, from which they receive a continuous current. The posts *S*, *S* receive the sinusoidal current furnished by the secondary coils, and deliver it from there by means of conducting-wires to the desired points. *B* is the armature, which is provided with a pulley, by means of which it may be operated by a small motor. *C*, *C* are teeth projecting from the armature. Both the field-frame, cores, and armature are made up of laminated iron.

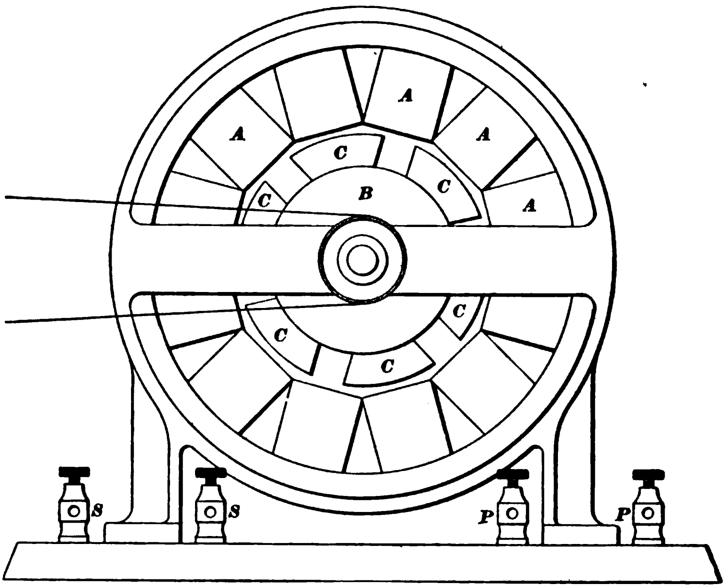


FIG. 53.

If, now, the primary coils have a current circulating through them, they will magnetize the cores of the spools *A*, *A*. The magnetic lines of force thus produced remain stationary in the cores as long as the armature is stationary, but, as soon as the latter begins to rotate, the lines of force will shift from one side of the spools to the other, and will cut the wires in the secondary coils first from one and then from the other side. It is clear, from what has already been said about induction, that an alternating E. M. F. must be produced in the secondary coils, and that, by giving suitable proportions to the projections on the armature surface, the resulting-current-waves may be made sinusoidal. At the speed of 4,800 revolutions per minute, the machine will deliver a current having 1,920 alternations per second.

THE INDUCTION-COIL.

73. Action of an Induction-Coil.—Another apparatus that also produces alternating currents for therapeutic purposes is the **induction-coil.** For a certain period it played the leading part in electrotherapeutics, when it was used as a cure-all. It was then small in size and altogether inefficient; at present it occupies a prominent position, but for other reasons. It has now found its proper, though more limited sphere, and is able to fulfil its functions much more satisfactory, because its effects are better understood and it is constructed on more scientific principles.

The action of an induction-coil is based on the phenomena of mutual and self-induction, which have been fully explained. In an induction-coil, it is first a question of starting an electric current through a coil of relatively coarse wire, a **primary coil;** then to suddenly interrupt, or stop, the current. By reason of its self-induction, the coil will then momentarily be traversed by a current of a much higher E. M. F. To produce this increase in E. M. F. is the first prime requisite. The next step is to find means for a further increase in this E. M. F. This is accomplished by surrounding the primary coil by a coil made of fine wire, a **secondary coil,** containing numerous turns, the intention being to let the latter be acted on inductively, and thereby produce an E. M. F. in it many times higher than that of the original battery current. From a therapeutic standpoint, the secondary coil is the more important of the two; but electrically considered, the primary coil forms the foundation of the whole apparatus and must be considered first.

Let Fig. 54 (*a*) be a diagrammatic view of a solenoid of numerous turns, showing its connections to a voltaic battery and to the electrodes held in the operator's hands. The solenoid P is, by means of wires g, g, attached to the electrodes E_1, E_2, and by wires *e*, *e* to battery *B*. A key *K* makes it possible to suddenly close or open the circuit. On this key being depressed, the battery will send a current through the solenoid, but only to a small extent through the electrodes E_1, E_2. This is because the resistance of the operator's body is so high, in comparison with the solenoid, that only a small current will flow through same and not of a strength sufficient to make itself felt. The arrows indicate the direction of the current. This current does not gain its full strength at once, because a counter E. M. F. is

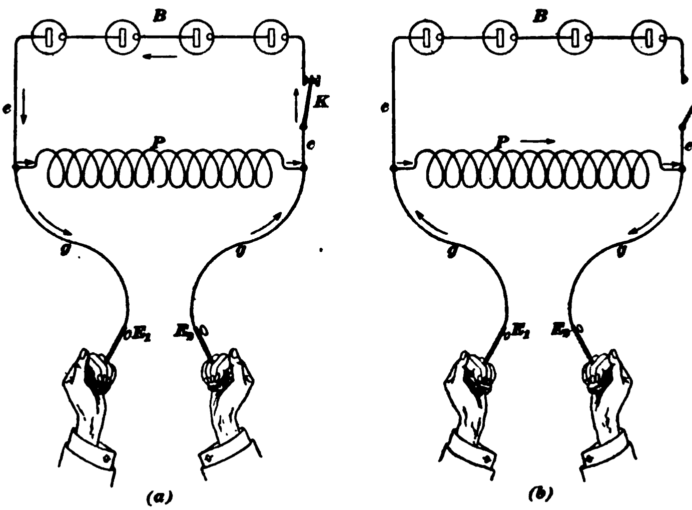


FIG. 54.

started in opposition to the impressed E. M. F., opposing the sudden passage of a current through the solenoid.

When the key is released, as shown in Fig. 54 (*b*), the circuit is open and no current passes from the battery. But the lines of magnetic force with which the solenoid was surrounded will suddenly collapse and induce a strong E. M. F. in the solenoid. This E. M. F. is now tending to act in the same direction as the battery current and to maintain the latter. But as communication with the battery is prevented by the open key *K*, it will follow the only path left, that through the electrodes E_1, E_2, and the operator will now feel a distinct shock, that of the *extra current*, previously described. The reason for this is that the existing lines of force contract with great rapidity, because no counter E. M. F. is interfering; and as the induced E. M. F. rises in value in proportion to the rapidity with which the lines close in, it follows that the E. M. F. now produced will be greatly in excess over that of the battery current. It will be noticed, in Fig. 54 (*b*), that though this E. M. F. acts through the solenoid in the same direction as that of the battery current, its direction through the conductors *g*, *g* and electrodes E_1, E_2 is in a direction opposite to that indicated in Fig. 54 (*a*).

74. Eddy Currents.—As we have shown that it is not only a question of the rapidity with which the lines of force contract when the circuit is broken, but also of the quantity of

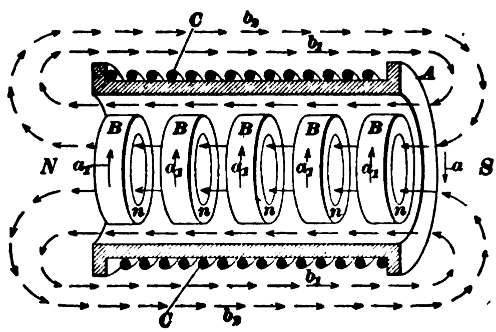


FIG. 55.

the active lines, it is clear that any means that will materially increase their number will be of value. As iron offers a better path for the lines of force than air, the interior of the solenoid, or coil, is always filled with a core of iron. This decreases the resistance of the magnetic circuit and thereby indirectly increases the magnetic flux through the coil.

Unless this core is properly subdivided, the advantages gained by its introduction will be entirely lost. It matters little whether or not this iron core consists of a solid rod of iron so long as the current that is flowing through the coil does not change its direction. But if the current is interrupted, or alternating, the case is different; then provisions must be made to prevent the starting of **Foucault's** or **eddy currents** in the core. This will be better understood by means of Fig. 55. *A* is the spool on which the coil *C* is wound. They are both shown in a cross-sectional view, the front half being removed. In the interior are placed small iron rings *B*. If, now, a current is flowing through the coil in the direction of the arrow *a*, lines of magnetic force will be flowing through and along the coil in the direction of the arrows b_1 and b_2; though only two of these lines are shown to pass through the iron rings *B*, *B*, we must suppose that these rings are filled with such lines.

75. Production of Eddy Currents.—As long as the current in the coil *C* is flowing uniformly, no effects are produced in the core rings *B*; but when the current is reduced in strength or stopped altogether, the lines of force will contract and the lines b_2 cut across the rings *B*, *B* in order to return to the coil, and consequently produce an E. M. F. in the rings that will act in the direction of the arrows a_1. These E. M. F.'s *a* and a_1 act in the same direction.

The E. M. F. in each of the rings *B* will start a current that will flow in the direction of the coil current. The cross-sectional area of the rings being large and their length small, their resistance will be practically nothing, and it will require a very small E. M. F. to set a heavy current flowing through them.

76. When a current begins to flow through the coil *C*, or an existing current is increased in strength, the lines b_1 and b_2 will expand inwardly through the rings *B* and cut across them from a direction opposite to the former. An E. M. F. will then be produced in the rings *B* acting in a direction contrary to that in the coil. In the latter case, the E. M. F. produced in the ring will not be as great as when the current was interrupted, because the increase in current-strength is at a much lower rate than its decrease when the circuit is broken.

These currents that are set flowing in the rings *B*, *B* are termed *Faucault's* or *eddy* currents and their effects are twofold. On starting a current through coil *C*, currents will flow through the rings in a direction opposite to that in the coil. The magnetic field of the rings will, therefore, also be of opposite polarity to that of the coil. For instance, if the end of the coil marked *S* is a south pole, the right side of the rings marked *n*, will be north poles. They will, therefore, tend to counteract and diminish the field of the coil, thus delaying the increase in current-strength. When the current is stopped, the currents in the rings will flow in the same direction as the coil current, and the magnetic fields of the rings will, therefore, also be in the same direction as that of the coil and will tend to maintain its magnetic field and delay the retreating lines of force.

Another disadvantage of the eddy currents is their heating effects. This is an important point, as the temperature that these currents produce will not only heat the core through which they flow, but also the surrounding coil. It will thereby increase its resistance and it may also, in some cases, heat the coil sufficiently to endanger its insulation.

When a core is made of a solid iron rod, we may imagine the same to consist of numerous small rings and that each of these rings is subjected to local E. M. F.'s. Electric currents will therefore flow along the whole length of the core in directions parallel with the coil current. We can see that in this instance the result will be even worse than with the separate rings, because the cross-sectional area is so much the larger.

77. Prevention of Eddy Currents.—To prevent these eddy currents, the same means are used as are adopted when the current through any electric circuit is to cease—that is, to break the continuity of the circuit. This is obtained by subdividing the larger rod into a great number of smaller ones, by making the rod of a collection of thin wires all of the same length. These rods are insulated from one another by a coating of varnish or are left bare, simply relying on the resistance of their oxidized surfaces and that of the intervening air to prevent the circulation of eddy currents. It is seen that, by this arrangement, the lines of force emanating from the coil have a perfectly free path to pass longitudinally from one end of the core to the other, while the transverse path along which the eddy currents would be inclined to flow, is cut up in minute sections.

78. The Spring Interrupter.—We have seen that the increased E. M. F. that produces the extra current is active only when the current through the primary coil is stopped. If it is desirable to produce a series of these high electromotive impulses, it is consequently necessary to successively start and stop the current through the primary coil or to constantly reverse the current, that is, use an alternating current. Let us here consider the first of these methods.

In Fig. 56, *C* represents an iron core made up of a bundle of fine iron wires and *P* a primary coil consisting of numerous turns of insulated copper wire. The operation of the primary coil is as follows: The battery *B* sends a current through the post *E* and screw *K* to the contact *D* on spring *F* and then through the latter to coil *P*. The current circulating through the coil is

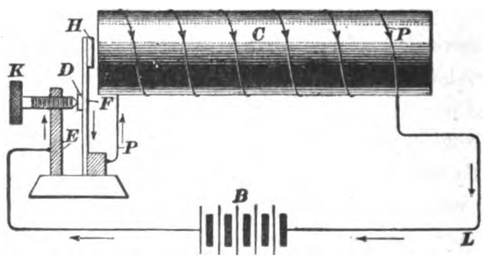


FIG. 56.

again the means that will produce a magnetic flux through the core *C*, making a magnet of the latter with a south pole to the left. When the attraction between the magnet and the iron disk, or armature, *H* on spring *F* is great enough to cause a motion of the latter, it will bend away from the screw *K*, thereby breaking contact between it and the platinum contact *D* on the spring. At this moment connection between the battery and coil is broken and the latter will be the site of an extra current, as already described. When this ceases, the core *C* will lose its magnetism and will be unable to any longer attract the armature *H*, which will move to the left and thereby again establish contact between *D* and *K*. A current will again flow through the coil *C*, which will magnetize the core and attract the armature *H*, when the circuit will be broken and the whole procedure repeated as before; the spring *F* will, therefore, be a means for automatically sending unidirectional, interrupted currents through the coil *P*. The combination of the spring *F* with contact screw *K* is termed a **spring interrupter**.

79. Breaking Contact.—If, at breaking contact, the coil shall develop a high E. M. F., it is evident that the interruption of the current must be accomplished with great suddenness. It would seem that the spring interrupter would be able to fulfil these conditions, but this is not quite so. There are certain drawbacks connected with this combination that must be eliminated. It is found that, at the moment the spring breaks contact, the resulting extra current is of an E. M. F. high enough to enable it to cross the intervening air-gap by means of a spark. This spark heats the air and breaks down the resistance of the gap, making it possible for a current to pass across even after the contact is broken. The result is that instead of the current being suddenly interrupted, it is only gradually decreasing; hence, it is unable to produce the high E. M. F. desired. It is, therefore, necessary to seek means whereby to prevent the sparking at contact *D*, which is found in an appliance called a **condenser**.

80. Function of an Air-Chamber.—A condenser has very much the same function as an air-chamber when inserted in a long pipe through which water is quickly flowing. It is well known that when the flow of water through a pipe is suddenly stopped, as, for instance, by the closing of a valve, the inertia of the water tends to maintain the flow and to bodily carry the pipe along in the same direction in which the water was flowing. That this longitudinal pull of the pipe must seriously strain its joints and connections, and that, therefore, a frequent starting and stopping of the flow must eventually cause a break somewhere in the pipe, can easily be seen.

To prevent this, long pipes are usually provided with what is called an *air-chamber*, as shown at *d*, Fig. 57. In this figure *T* is a tank which supplies the pipe *a* with water. If now the valve *b* is shut quickly, the water will tend to continue its motion and carry the pipe along in the direction of the arrow, and thus cause somewhat of a stress in the former. The function of the air-chamber is to prevent the sudden stoppage of the water, by giving it an opportunity of entering the chamber *d* through the pipe *c*. The air which is contained in the upper part of the chamber will then be more and more compressed by the water, thus acting somewhat like a spring, in

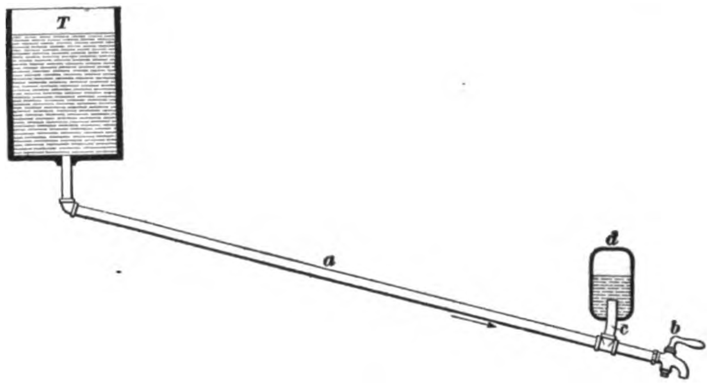


FIG. 57.

making the water give up its energy slowly and perform a certain work of compression over a more or less extended period, instead of a sudden blow.

81. Hydraulic Analogy of a Condenser.—In Fig. 58, the air-chamber has been replaced by a cylinder *R* with piston *e*, which is kept in a middle position by the two compression springs *a*, *b*. In place of the tank we have here a rotary pump, *B* as described in *Direct Currents*. When the latter is set in rotation, it will send a current of water through the tube L_1 into the coil *P* and back again through tube L_1. The valve *F* regulates the current-strength and two branch tubes a_2 and b_2 establish communication between the tube L_2 and cylinder *R*, whereby piston *e* will be made to move either to the right or left, depending on which side a surplus pressure exists.

Suppose now that the valve *F* is wide open and that the water is set flowing through the coil *P*, and then the valve suddenly shut. The water in the coil will seek to continue its motion and thereby tend to create a vacuum at the valve *F* and piston *e*. The latter will, therefore, have an excess of pressure on the left and will be compelled to move toward the right and compress spring *b*. The energy of the moving water column is now momentarily transformed into compression of the spring *b*.

As soon as the current comes to a standstill, the spring will at once seek to expend the energy delivered to it by again pushing the piston *e* to the left. The water in the coil *P* is obliged to follow and the latter will momentarily be traversed by a

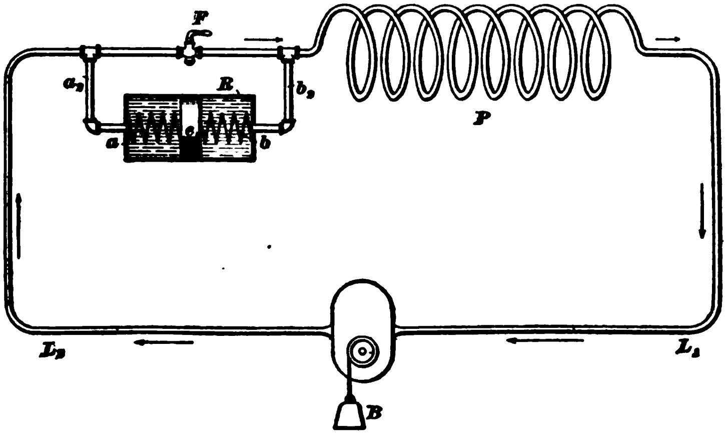


FIG. 58.

reversed current. This reverse current will also take place in the tube L_2, motor *B*, and tube L_1. If the valve *F* is opened before the reverse current has ceased, the current through L_1 will, in starting its flow, have to overcome this reverse current.

82. Construction of Condenser.—The action of a condenser is almost exactly the same as that of the cylinder *R* in Fig. 58. It will not be necessary to here enter into a detailed description of the condenser, as this will be done fully in *Electrostatics*, where "Leyden Jars" are described. It will be enough to say that a condenser may be considered as a short conductor with a very large surface, employed for storing up electrostatic charges. If used for induction-coils, it consists of a number of sheets of tin-foil *a* and *b*, Fig. 59 (*a*), between which are inserted sheets of paraffined paper *c*, *c*. Each sheet *a* has a tongue of tin-foil a_1 on the left and sheets *b* corresponding tongues b_1 on the right side. All tongues belonging to sheets marked *a* are joined together and connected to a wire a_2, as shown in Fig. 59 (*b*), and the sheets *b* are similarly connected to the wire b_2. The sheets *a* are thus united to each other, but insulated from the sheets *b*. It is therefore possible, for instance, to have a positive charge on the sheets *a* and an equal negative charge on the sheets *b*, without the two charges being able to unite, though they will have a mutual inductive influence on each other. In la·ge coils, the amount of tin-foil used for condensers may amount to over 300 square feet.

83. Condenser and Induction-Coil Combined.—Let us now combine a condenser, as described, with an induction-coil of the form shown in Fig. 56. This has been done in Fig. 60, in which *R* is the condenser, connected by wires a_2 and b_2 with the post *E* and spring *F*, respectively. The other parts are lettered in the same manner as in Fig. 56 and need no additional description.

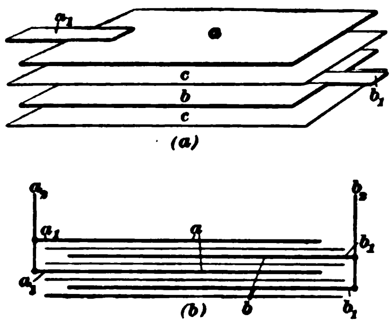


FIG. 59.

As soon as the current begins to flow through the screw *K* and contact *D* into the coil *P*, the core will be magnetized and attract the armature *H*. The circuit thus being broken at *D*, the lines of force close in around the coil *P* and tend to set an extra current flowing. In Fig. 56, the current was able by means of its high E. M. F. to bridge across the air-gap at *D* by means of a spark. In the present instance, the current is offered a path of much less resistance by going into the condenser. The result will be that the current, as if possessing inertia, will continue its motion and flow through conductor L_1, battery *B*, conductors

L_2 and a_2, into the leaves a of the condenser. Simultaneously, the other end of the coil has sought to withdraw electric charges from the leaves b of the condenser through the conductor b_2. The leaves a will be positive and b negative. As soon as the energy of the current has been taken up by the condenser, the latter will at once seek to discharge itself by sending a current through the coil in the reverse direction. The positively charged leaves a will send a current through the battery and conductor L_1

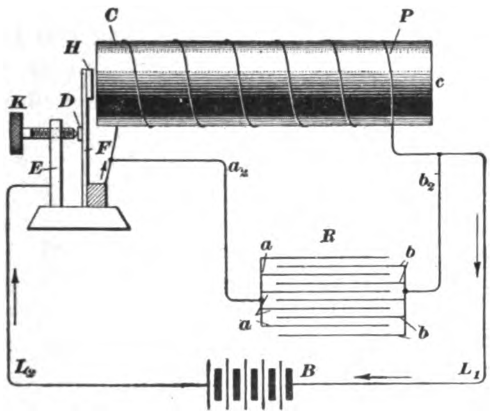


FIG. 60.

into the coil from the latter through conductor b_2 into the negatively charged leaves b.

The main purpose sought by introducing the condenser in the circuit was to present an open path for the extra current, whereby sparking at the spring contact might be prevented. The result would be that the extra current would cease abruptly and thus attain a much higher E. M. F. We see that the condenser not only provides this path, but does more. It furnishes a reverse current and thereby still more effectively demagnetizes the coil core.

When the rate of interruption is such that the spring F will make contact before this reverse current has ceased, the battery will momentarily be compelled to work in opposition to this current. The effect will be that the closing current will be still further weakened and the extra current made more prominent.

84. Curve of Self-Induction.—It is apparent that the self-induction of the primary coil plays quite an important part in varying the E. M. F. of the primary current, by reducing it when the current begins to flow and augmenting it when interrupted. Fig. 61 (*a*) may represent the induced E. M. F. in a primary coil, when *X X* is the zero-line, and the curves above and below the line represent, respectively, positive and negative potentials. The curved line *L M N O* shows that the counter E. M. F. of self-induction is at its maximum strength at the moment when the circuit is closed, that is, at *L M*, and that it gradually decreases while the current is gaining strength, and the spreading lines of force are reaching their final positions, until it reaches *N O*, where it suddenly goes to zero. The

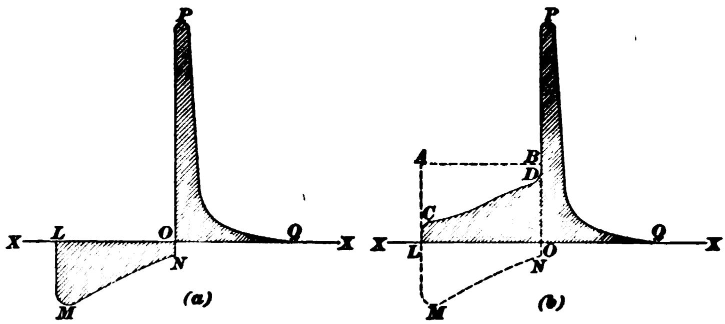


FIG. 61.

current is interrupted at this point, and the E. M. F. of self-induction instantly rises to a high positive potential at *O P*, caused by the sudden collapse of the lines of force, whence it falls back just as suddenly as it rose, and finally dies away at *Q*. To illustrate the difference between these electromotive forces, we may consider the counter E. M. F. at *L M* to be 1 volt and during $\frac{1}{100}$ part of a second to be falling to zero, while *P O* may be 6 volts and be reduced to zero in the $\frac{1}{1000}$ part of a second. It should be understood that this curve does *not* represent the *current* in the primary coil, but the E. M. F. of self-induction, which may or may not assist the impressed E. M. F., as will be shown more fully further on.

85. The Secondary Coil.—So far we have only considered the primary coil in combination with an iron core. We will now go a step further and place a secondary coil outside the primary and investigate how this secondary coil is affected inductively by the primary coil and its core.

In Fig. 62, *S* represents a secondary coil wound on the outside of the primary coil *P*; both coils are supported by a spool *O* of insulating material surrounding the iron core *C* in its

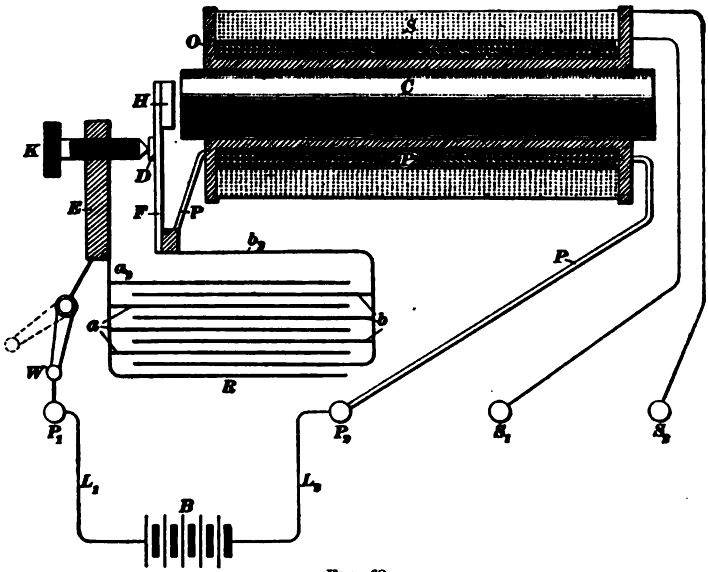


FIG. 62.

interior. A switch *W* connects the post *E* with the terminal P_1, and the terminals P_1 and P_2 are joined to the battery *B* by means of wires L_1 and L_2. The terminals S_1 and S_2 of the secondary coil are not for the present connected with each other; the secondary coil is therefore open.

86. Function of Secondary Coil.—Under these conditions the secondary coil may be considered simply as an addition to the primary coil, without being directly connected with it; that is to say, it is subjected to the *induction* of the make-current, but does not itself conduct any current. When, therefore, a current begins to flow in the primary coil and the magnetic flux begins to spread, an E. M. F., similar to that shown by the curve *L M N O* in Fig. 61 (*a*) is created in the secondary coil; but with this great difference, that while the E. M. F. in the one instance is in opposition to that of the primary current, and therefore powerless to do more than diminish it, in the present case it has no opposition, and is therefore able to utilize its full pressure in sending a current through the secondary coil, if its circuit is closed. It is well to emphasize this difference still more by saying that, while the make-current is flowing, there exists in the primary coil an increasing *positive* E. M. F., and in the secondary coil an increasing *negative* E. M. F. This relation between the E. M. F. continues until the current is interrupted at the point *O P*, Fig. 61 (*a*). Then the conditions in both coils are the same, because neither of them is connected with the primary battery. The closing in of the magnetic flux has, therefore, the *same* effect on both coils, that is, it creates in each a positive E. M. F. of the form shown at *O P Q*, Fig. 61 (*a*). In the primary coil, this means a *continuation* of the impressed E. M. F., but of a greater magnitude, while in the secondary coil it means an E. M. F. in opposite direction to that in the latter existing E. M. F. We may conclude from this that, with an open secondary circuit, both coils are subjected to the same inductive influences, but with different results, so that, while the E. M. F. in the primary coil is of a direct and intermittent nature, in the secondary coil it is alternating. In both cases the waves are dissymmetrical, because the waves produced at breaking-contact are of a greater magnitude.

87. E. M. F. of Secondary and Primary Coil.—If, as is supposed, the coils are subjected to the same inductive influences, the induced E. M. F. should be the same; provided that both coils contain the same number of turns. Ordinarily the secondary coil consists of many more turns than the primary, and the same magnetic flux would therefore produce a higher E. M. F. in the secondary coil, the increase being directly proportional to the added number of turns. It is easy to see why this must be so. Take, for instance, a piece of wire

4 inches long, and let 100 lines of force move across it, producing a certain E. M. F. in the wire. If now a wire 400 inches long is so arranged or wound that the space it occupies is not more than 4 inches in length, the whole wire will be simultaneously cut by the 100 lines of force; that is, every 4 inches of the wire will have the same E. M. F. produced in it as the original short piece. The long wire will therefore have an E. M. F. 100 times larger than the small wire. Thus the primary coil may, for instance, consist of 80 turns, while the secondary may contain 4,000 turns; hence, the E. M. F. in the secondary coil should be 50 times as great as that in the primary. Fig. 61 (*a*) might represent these electromotive forces in the secondary coil if the vertical lines *L M*, *N O*, and *O P* were made 50 times as long, and the curved parts connecting them drawn parallel to *M N* and *P Q*. If *L M* and *O P*, respectively, represent 1 and 6 volts, then the corresponding values for the longer secondary coil would be, respectively, 50 and 300 volts.

88. Effect of Secondary on Primary Coil.—So far the secondary coil has had no effect on the primary coil, because no current has passed through the former; but let the terminals S_1 and S_2, Fig. 62, be connected to some external circuit, then the conditions will be materially altered. The high E. M. F. generated in the secondary coil has now an opportunity of starting a current; but in doing so, it will immediately create a M. M. F. which will not alone send a magnetic flux through the secondary, but also through the primary coil. It will set up a counter E. M. F. in the secondary in opposition to that of the secondary current, while, in the iron core, it will set up a magnetic flux in opposition to that produced by the primary current.

That the current in the secondary coil should have this obstructing effect on the flow of the primary current ought not to come entirely unexpected, as it must derive its E. M. F. from some source. It is therefore evident that the energy displayed in the secondary coil is taken from the primary current after contact is made. The extent of these reactions, due to the secondary coil, depends upon the strength of the current flowing in the latter, which is again controlled by the resistance of the coil and the external circuit, and by the self-induction of the coil.

89. Reduction of Voltage in Secondary.—We saw above that the E. M. F. in the secondary coil at breaking might be 300 volts, when no current was flowing; but this voltage suffers a very great reduction when a current is permitted to circulate. On the insertion of a comparatively low resistance, the potential difference at the secondary terminals may be only two or three volts. Even with a resistance of 1,000 ohms, the E. M. F. would be very low, ordinarily from 10 to 15 volts, as long as we deal with small coils; with large coils these values are of course much greater. This is caused partly by the reaction of the secondary current on the primary circuit, but principally by the self-induction in the secondary circuit itself. At the time when the induced E. M. F. is at its maximum, and when a heavy current *might* flow, it is most effectually stopped by the powerful choking action of the coil, which does not permit a sudden rise or a sudden fall of pressure. In addition to these inductive reactions, the E. M. F. will also suffer a great reduction by the resistance of the very long, thin wire of the secondary coil. The secondary current, therefore, after it has been subjected to all these influences, emerges not only in a very much enfeebled condition, but the character of its waves has also undergone a great change; the rough edges have, so to speak, been cut away.

90. In their present form they may appear as the waves shown in Fig. 63, in which the changes are seen to be less

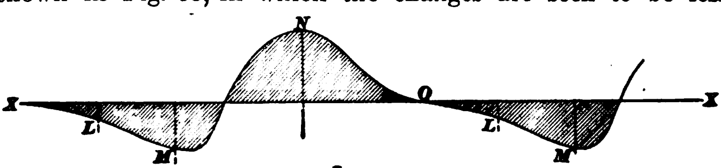


FIG. 63.

abrupt. Here we observe that, when the spring makes contact at point X, the pressure begins to increase gradually, but is not permitted to reach its maximum value before the contact at M

is broken. The E. M. F. is now suddenly reversed and rises to its full value at *N*, whence it slowly descends until point *O* is again reached, contact made, and the cycle repeated. A secondary coil made of long, thin wire, by reason of its high self-induction, has a soothing effect, but even then we may see that the wave is always steeper on breaking contact; *in fact, it is impossible to make the waves of the induced E. M. F. of a symmetrical form.* Should it be desirable to have the waves act more abruptly, the number of turns in the secondary circuit should be reduced, thereby reducing its self-induction and resistance. In addition to this, the number of interruptions per second should be lessened, giving the current time to reach its full strength.

91. E. M. F. Curve of the Battery-Current.—As Figs. 61 (*a*) and 63 give the curves of the induced E. M. F. only, it may be well also to show the E. M. F. curve of the battery-current after it has been affected by the counter E. M. F. of self-induction in the primary coil. Let the line *A B* in Fig. 61 (*b*) represent the available E. M. F. of the battery, and the dotted line *L M N O* the counter E. M. F. arising on making contact. If the primary coil had been devoid of this self-induction, the line *A B* would show the E. M. F. of the primary coil; but as the E. M. F. is acting in opposition, the latter must be deducted from the former, and the E. M. F. of *L C D* remains, which, in addition to the curve *D P Q* of the extra current, gives the whole active E. M. F. of the primary coil, if the secondary circuit is open. On closing the latter, the primary E. M. F. is affected more or less, depending on the inductive influence of the secondary coil.

92. Use of the Primary Current in Medicine.—The primary current is employed in medical treatment when the resistance is low and a larger volume of current than the secondary coil can furnish is required. To show how a resistance affects these dissimilar coils, let us suppose that the E. M. F. of the primary coil is 5 volts and its resistance 1 ohm, while the E. M. F. of the secondary coil is 100 volts and resistance 1,000 ohms. If the currents of these coils are sent through a galvanometer of 4 ohms resistance, we have, according to Ohm's law, in the first coil a current of : $\frac{E}{R} = \frac{5}{1+4} = 1$ ampere; and in the secondary coil, $\frac{100}{1,000+4} = .0996$ ampere. On increasing the resistance of the galvanometer to 50 ohms, the current in the primary coil is $\frac{5}{1+50} = .098$ ampere, and in the secondary coil, $\frac{100}{1,000+50} = .0952$ ampere, that is, the currents in the two coils are very nearly the same. But let the resistance be increased to that of the human body, or about 2,000 ohms, then the difference will be most marked. In the primary coil the current will now be $\frac{5}{1+2,000} = .0025$ ampere, while that in the secondary is, $\frac{100}{2,000+1,000} = .033$ ampere. In the latter instance the current in the secondary coil is more than 13 times the strength of that in the primary coil. It is therefore clear that, in order to apply percutaneously the "extra current" of the primary coil, the electrodes must be large and the skin well moistened to diminish external resistance.

In speaking of voltage and strength of this induced current, it is well to call attention to some points that are often misunderstood. It has, for instance, been claimed that a smaller quantity of electricity comes out of the primary coil than goes into it. We know from previous explanations that this is impossible; that, in fact, whatever quantity of electricity enters the coil will leave it again undiminished. This idea very likely has been based on the well-known fact that the current that enters the primary coil is smaller than it ought to be, if it simply depended on the resistance of the coil and the available E. M. F. of the battery. But it was shown in Art. **84** that the reason for this reduced strength was to be found in the self-induction of the primary coil.

93. Effects of a Dissymmetrical Alternating Current.—The E. M. F. in Fig. 63 is alternating; but notwithstanding this, its physiological effects may be that of an unidirectional current. The "break-current" is many times stronger than the "make-current." This break-current is the only one that acts on the tissues or organs; the dissymmetrical alternating current may, therefore, be said to be unidirectional. To understand this better, let us use as an illustration an air-pump, as shown in Fig. 64, in which *A* is a cylinder and *B* a piston moving from one end of the cylinder to the other.

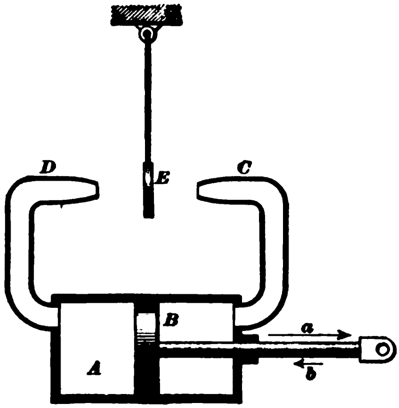


FIG. 64.

D and *C* are pipes connected with the ends of the cylinder, and *E* a vane suspended in the manner of a pendulum. If, now, the piston should begin a reciprocating motion with the same speed in both directions, it would produce effects similar to those of an alternating E. M. F. The air would escape alternately from the pipes *C* and *D* and blow against the vane, causing the latter to oscillate from side to side. This would correspond to the action of symmetrical alternating currents, when the effect of either terminal would be the same.

But suppose the piston to move with speeds corresponding to those indicated by the lengths of the arrows *a* and *b*. We may then imagine the piston speed towards the left to be so slow that the current of air escaping from *D* could barely be perceived, and that its influence on the vane would be negligible, while the air passing from *C* would be ejected with a high speed, forcing the vane strongly to the left. Considering the vane simply as a pressure-indicator, we would come to the conclusion that the air-pump produces a pressure on only one side of the piston, and that of an intermittent nature. Let the vane be now removed and a rubber tube slipped over the pipes *C* and *D*, transforming the whole into one continuous pipe in which, at some convenient point, a current-meter has been inserted. When the piston begins its uneven motion, the meter makes no distinction between the pressure on one side or the other. It merely indicates that so many cubic feet of air pass at each stroke of the piston, irrespective of its pressure. Judging from these indications, we should say an alternating current was passing and that the effects were the same in either direction.

94. Effects of Induction-Currents.—The same conditions determine the effects of the induction-current on the human body. It requires a certain pressure of the current to excite the muscles; to a pressure below this the muscles do not respond. When, therefore, an alternating current is flowing from a secondary coil, the effect on the muscles will be the same as that of the air-current on the vane. Though the current in *reality* is alternately flowing in both directions, *physiologically* it is unidirectional, and it will therefore make a difference which of the electrodes is placed on the muscle. On the other hand, when it comes to those effects where it is simply a question of current-volume, it is immaterial how the coil is connected with the body, as the same volume of electricity passes through either electrode. The case is then similar to the air-pump with both pipes connected by the rubber tube.

95. Effects of Changing the Number of Turns in Secondary Coil.—It must be remembered that by changing the number of turns in the secondary coil, the voltage and amperage will be changed according to certain fixed laws. For instance, by increasing the diameter of the wire and reducing the number of turns, the induced E. M. F. is necessarily reduced, while the amperage is increased. Other conditions remaining the same, the product of the two should be a constant. Therefore, a reduction of the wire diameter with an increased number of turns should necessarily be followed by a reduced amperage and an increased E. M. F. That this product is *not* a constant is caused by the self-induction of the coil; but, nevertheless, the tendency is in that direction, and when it is claimed, as it has been, that the length of the coil is immaterial, it is well to remember these facts as a general guide to the right use of the coil.

96. Variation of Electromotive Force in an Induction-Coil.—For therapeutic uses, it is important that the active part of the secondary coil is variable, so as to create a high or a low E. M. F. and to vary the strength of the current. It is also of advantage to be able to use the primary coil alone, or in conjunction with the secondary coil, as a curative agent. Fig. 65 shows the primary coil connected in such a manner that its induced extra current may be sent through the human body. P' and P'' are, as before, the terminals of the primary coil, while P''' is connected with the vibrating spring and also with one end of the primary coil. If, now, P'' and P''' are provided with conducting-cords and electrodes and the latter held in the

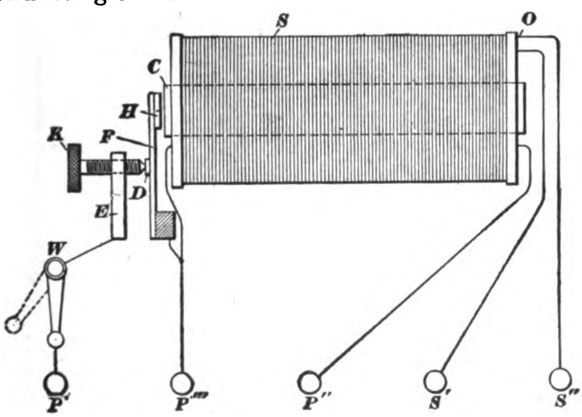


FIG. 65.

hands, a distinct shock will be felt when the spring breaks contact, because the human body is the only path left open by which the current may pass. On making contact no sensation will be felt, since in that case the voltage is very low, in fact, below the E. M. F. of the cells, as previously shown in Fig. 61 (*b*).

97. Another combination, in which the primary coil may be used singly or in conjunction with the secondary coil, is that shown in Fig. 66. Here the end p_2 of the primary coil and the beginning s_1 of the secondary coil, are joined to the spring of the contact-device *F*. The beginning p_1 of the primary coil is connected to the switch *W* and the latter eventually to the terminal P_2. The end s_2 of the secondary coil is connected to the terminal S_2. Between the terminals P_2 and S_1 we have now the E. M. F. of the primary coil, and between S_1 and S_2 the E. M. F. of the secondary coil alone. Finally, between the terminals P_2 and S_2 we have the combined E. M. F. of both coils. The contact-device F connects the end of p_2 of the primary coil with the beginning s_1 of the secondary coil, making one coil of both. It will therefore be necessary to use P_2,

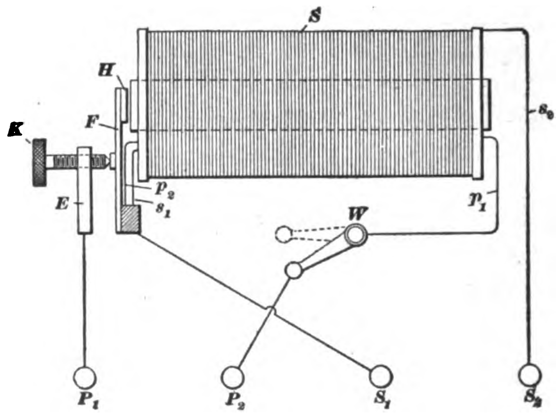


FIG. 66.

which connects with the beginning p_1 of the primary coil, and the terminal s_2 of the secondary coil, to have both coils connected as one.

98. E. M. F. Generated by the Secondary Coil.—It has been shown that the E. M. F. generated by the secondary coil depends upon the strength of the magnetic field and on the number of turns in the coil; likewise on the speed with which the magnetic flux fills and empties these turns, and on the number of interruptions per second. The strength of the magnetic field in the first place depends on the number of cells connected with the primary coil and the number of turns in the latter. With the primary coil and the magnetic flux in same considered as a constant, the E. M. F. of the secondary coil may be altered, either by changing the effect of the magnetic flux on it, or by altering the speed of the vibrator.

99. Dubois-Reymond Regulator.—The first of these methods—that is, varying the effect of the magnetic flux on the secondary coil—may be carried out in various ways. We will consider briefly the most important of these, as recent practise tends to abandon them all with one exception, the aim being to avoid complicated devices, when better and surer results may be reached by instruments constructed on more scientific principles.

One of the earlier forms of regulators for this purpose was of the so-called *Dubois-Reymond* type. In this the primary coil with its iron core was stationary, while the secondary coil was separate and could be moved away from the primary, enclosing it more or less according to the E. M. F. it was desired to develop in the secondary coil. It can easily be seen that a withdrawal of the secondary coil from the inductive influence of the primary coil must weaken the resulting E. M. F. in the former, because part of the secondary coil is entirely out of reach of the lines of force, and therefore inactive so far as producing an E. M. F. is concerned, but still influencing the current by means of the self-induction and resistance of the whole coil. The base of the coil is provided ordinarily with a millimeter scale which enables the operator to read off in millimeters the distance between the coils. It is claimed that by the use of this millimeter scale one can at any time reestablish with sufficient accuracy for clinical purposes the conditions which existed during former treatments. This is the only advantage of the scale, for as an indicator of current-strength it is without value, and must not be considered as such. An instrument of this class is often provided with several secondary coils, making it possible to substitute one of finer wire for others of coarser wire, while at the same time the primary coil remains stationary and unaltered.

Instead of having several loose secondary coils, there may be two or three such coils fastened permanently to the base, either of the coils being thrown into action by means of a switch, and each of them operated by its own vibrator, or by a vibrator which is common for all. This is the form of secondary coil now generally used.

100. Screening Effects.—It is not absolutely necessary to move the secondary coil out of the magnetic field in order to diminish its action; it may remain in its original position and the force of the magnetic waves be diminished before they reach the coil. We have already seen that the iron core had to be subdivided to prevent the formation of eddy-currents. The existence of these currents in conductors of large diameters has a screening effect on coils situated either inside or outside of said conductor, and may therefore be used as a means for weakening the action of the magnetic field. Ordinarily, a space is left open between the iron core and the spool, large enough to allow the insertion of a metal tube. If the tube is pushed in far enough to cover the whole length of the core, it reacts so strongly on the primary current that only a very feeble E. M. F. is generated in the secondary coil. To understand this, it must be borne in mind that the tube practically constitutes a secondary coil. It is true that, strictly speaking, it consists of one turn only; but this one turn is of a large cross-sectional area, and only a few inches in length, and consequently of very low resistance. When, therefore, the magnetic flux passes and repasses through the shield, it produces, although the E. M. F. is small, rather powerful secondary currents and a M. M. F. in a contrary direction to that of the primary coil. It therefore counteracts the effects of the primary circuit, and the result is that only a feeble magnetic flux reaches the secondary coil. A gradual withdrawal of the tube of course dimishes its reactive influence and permits the E. M. F. in the secondary coil to increase. This tube need not necessarily be placed around the core; it may be situated between the primary and secondary coil, or over the secondary coil alone. In either case the action of the tube is the same. In a scientific faradic apparatus the shield is not used.

101. Modern Methods of Regulation.—The first of these methods of regulations is much used in modern induction-coils. The aim has been though to avoid all loose and movable parts, as being a source of confusion and uncertainty, and to place all the coils in a fixed position. When the various coils are to be thrown in and out of action, it is effected by the aid of switches to which the terminals of the coils have to be connected. The positions of the coils may be such that they are either placed inside of one another or side by side.

An example of the first arrangement is shown in Fig. 67. The terminals of the battery B are attached to P_1 and P_2, which in turn connect with the pole-reverser V. The current flows from V through the wire w_2 to the contact-spring F and the post F'_1, and thence through wire p to the primary coil P, from which it returns to the reverser through the wire w_1. The secondary coil S_1, made of very fine wire, has one of its ends

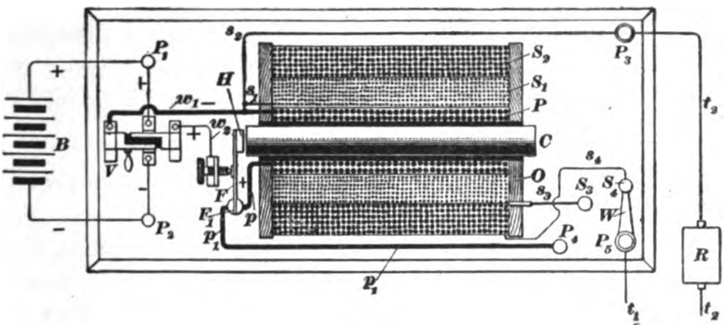


FIG. 67.

joined to the wires w_1 and s_2; the latter is connected with the terminal P_3. The other end of S_1 and the beginning of the coil S_2 are both attached to the wire s_3 that is connected to the contact S_3. The end of the coil S_2 is by means of the wire s_4 united with the contact S_4; and finally the post F_1 is connected to the contact P_4 through the wire p_1. The terminal of the switch W is P_5, which, together with the terminal P_3, constitute the terminals of the induction-coil, to which the conductors t_1 and t_2 are attached.

In the present instance, the secondary coil has only two subdivisions; but in all modern faradic batteries there are six, made up of three different sizes of wire. The switch with its connections will not be affected by this increased number, and the arrangement shown in the figure will in the main be retained. The operation of the coil is the same as before; the new features are to be found in the pole-reverser *V* and the switch *W*. The former will be described later on; it will suffice at this point to say that, by moving the handle to the other side, the wire w_2 becomes negative, instead of wire w_1, as at present. When the switch *W* is connected with the contact P_4, the primary current alone is received through the conductors t_1 and t_2. Turning the switch to the contact S_3, the alternating current of the secondary coil S_1 is sent through the terminals; and finally, when the switch reaches the position indicated in the figure, the united E. M. F. of both the coil S_1 and the coil S_2 will be received.

The current may be regulated by means of the rheostat *R* in the primary or secondary circuit to any desired strength, and any sudden fluctuations may thus be avoided when changing from one coil to another. The switch need not necessarily be placed on the base of the induction-coil; it is frequently placed on one end of the spool.

102. Compound Secondary Coils.—Experience proves that a limited number of secondary coils do not serve the purposes for which they are intended in electrotherapeutics, and that certain effects aimed for, notably those of a sedative influence, are altogether impossible. Various combinations of coils have been suggested as fulfilling all requirements, and as these agree pretty closely, it is necessary to give but one of them. Hence, the following arrangement suggested by one of the leading practitioners in that line, will suffice:

The primary coil,	made of No. 21 wire,	84 yd. long.
First secondary coil,	made of No. 21 wire,	100 yd. long.
Second secondary coil,	made of No. 21 wire,	150 yd. long.
Third secondary coil,	made of No. 32 wire,	300 yd. long.
Fourth secondary coil,	made of No. 32 wire,	500 yd. long.
Fifth secondary coil,	made of No. 36 wire,	500 yd. long.
Sixth secondary coil,	made of No. 36 wire,	1,000 yd. long.
Adding, total length of secondary coil equals 2,550 yd.		

The end of each coil is joined to the beginning of the adjoining coil and each junction connected with a contact-button.

103. Methods of Effecting Combinations.—There are various means for effecting the desired combinations of the secondary coils, or the primary and the secondary coils. A device of this kind, with its connections, is shown in the diagram in Fig. 68. The studs *Z* are supposed to be arranged

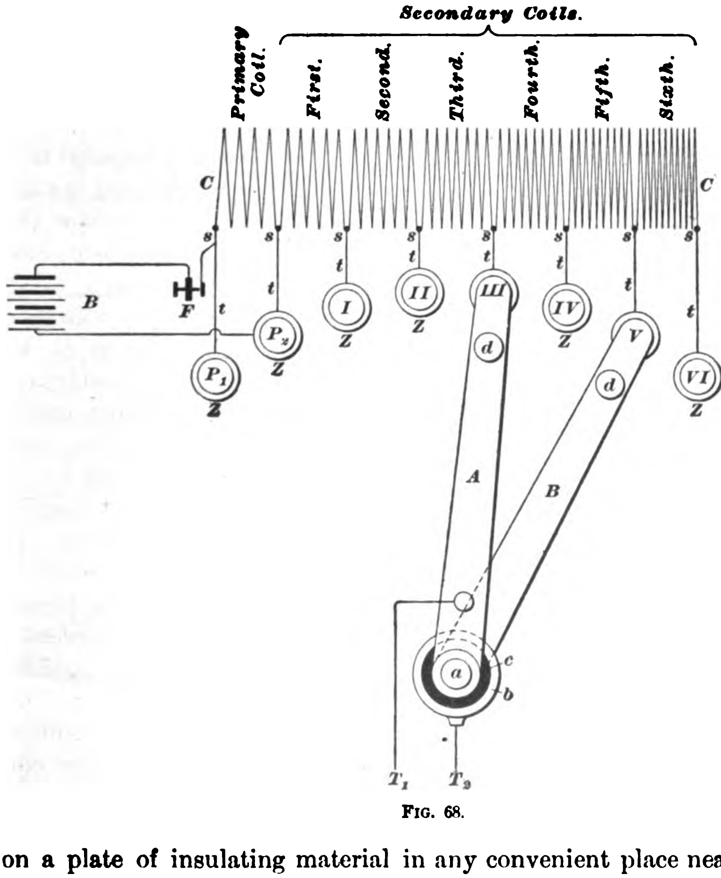


FIG. 68.

on a plate of insulating material in any convenient place near the induction-coil, and the arms *A*, *B* are supported by the plate in such a manner that they can be moved from stud to stud by means of the small knobs *d*, *d*. The arm *A* swings on the pin *a*, which is surrounded by a bushing *c* of insulating material; it is therefore insulated from the ring *b* to which the other arm *B* is attached. The conductors T_1 and T_2 leading to the electrodes are connected in any suitable manner to *A* and *B*, respectively. In this instance they are shown, for the sake of clearness, fastened directly to the arms. The primary battery *B* is connected to the vibrator *F* and the stud P_2, while the stud P_1 is joined to the primary coil near *F*.

All the coils are connected with one another so as to make one continuous coil, and the junctions of the coils are again joined to the studs by means of the conductors *t*. One end of the last is, as one end of the first coil, likewise joined to a stud, as shown in the figure. The coils are in reality supposed to be wound so as to surround each other, as in Fig. 67, and not side by side, as indicated in this figure. It can easily be seen that by thus insulating the arms *A*, *B* from each other it is possible to select any separate coil and to use its current alone or to add any other coil that may be necessary for the proper voltage or strength. By placing the arm *A* on P_1, and *B* on P_2, the primary coil alone may be utilized, or the first secondary coil may be added by moving *B* to stud *I*. Any further motion of *B* towards the right adds a coil for each stud it passes, until, when it reaches stud *VI*, the whole coil is included in the circuit. In the position of the arms shown in the diagram, only the fourth and fifth secondary coils are in the circuit. By moving arm *A* to *IV* the fifth coil alone would be in use.

It has already been shown in Arts. **115-122**, *Direct Currents*, how the cells that operate an induction-coil may be combined to give the desired voltage.

104. The Speed of the Vibrator.—Having considered the first method of varying the E. M. F. in the secondary coil, we will now proceed to the second, that of varying the speed of the vibrator.

The contact-spring, shown in Figs. 56 and 67, does not admit of much variation in regard to frequency. The usual method is to advance the screw *K* towards the spring, thereby bending the spring out of its original position, and causing it to exert a heavier pressure against the platinum contact *D*. The distance through which it moves is now shorter and its motion quicker, resulting in an increased number of vibrations per second. The increase in frequency obtainable in this manner is not very great, and it is seldom that the original speed can be doubled. It may be improved somewhat by adding another screw K_1 near the base, as shown in Fig. 69, thereby shortening the active part of the spring. The frequency of a good spring-vibrator varies from 150 to 300 interruptions per second.

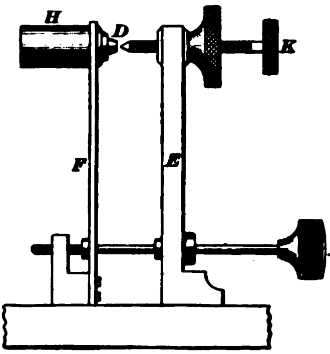


FIG. 69.

105. Ribbon Vibrator. If it is desired to increase the frequency still further, a *ribbon vibrator*, such as is illustrated in Fig. 70, may be used. The steel ribbon *r* is fastened to a post *a* and supported by another post *b* through which the ribbon passes. The contact-screw *c* regulates the pressure and the rate of vibration. An additional means for regulation is found in the lever *e* to which one end of the ribbon is connected. The screw *d* engages this lever and can, by forcing it away from the

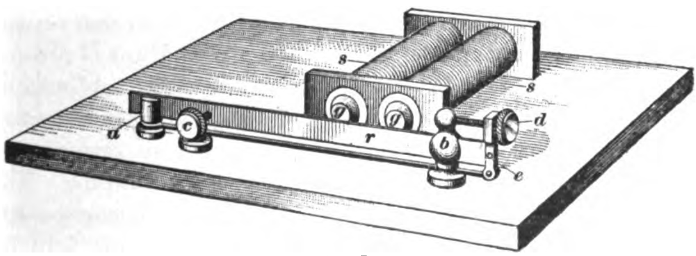


FIG. 70.

post *b*, subject the ribbon to an increased tension, followed by a still higher rate of vibration. The iron cores are shown at *g*, *g*, and *s*, *s* are the secondary coils, one of which is made of rather coarse wire. The ribbon vibrator is connected with the fine-wire coil, and gives an alternating current of rather high frequency, in which the waves are smooth and devoid of any abrupt changes.

The other coil is used in combination with a slow vibrator separately illustrated in Fig. 71, wherein *F* is a spring with an iron armature *H* and an extension *D* carrying a small weight *W*. The weight can be fastened in several positions to correspond with the changes in the rate of vibration. The contact-screw is shown at *K*, and *C* is a small electromagnet operated by the primary current. When placing the weight *W* at the extreme right, the vibrations are the slowest obtainable. Moving the weight towards *K* increases the rate of vibration, and if *W* be taken off altogether the make and break is very rapid. Since the coil is made of a coarse wire and with few turns, the current will necessarily be of a low E. M. F. with sudden changes.

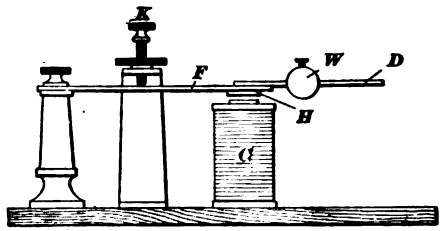


FIG. 71.

106. High-Speed Vibrator.—A vibrator that is claimed to be capable of varying the rate of the interruptions from 50 to 1,500 per minute, is illustrated in Fig. 72. The head *A* of a spool is provided with a disk *B* which is free to revolve on the pin *O*. The disk carries a spool *C*, and a pendulum *D* pivoted in the bracket *P*. The pendulum is provided with an adjustable weight *W* and an iron armature *H*. The slotted lever *E* carries, at one of its extremities, a pin *K* adapted to engage the spring *F* and push it more or less against the pendulum. The lever is pivoted on the post *L*, and its slotted end engages a stationary pin *M*. When the disk *B* is turned to the right by means of the handle *N*, the pin *K* is swung to the left, thus shortening the active part of the spring, and making it stiffer. The rate of vibration is therefore increased. On turning the disk to the left the spring is not only made weaker, but the pendulum hangs in a position more nearly vertical, and exerts a smaller pressure against the spring. When the handle *N* has finally reached its extreme position at the left, the pendulum will come to a complete stop.

107. Effect of Excessive Frequency of Vibration. It might seem, at first glance, that if a high E. M. F. were desirable, the frequency of vibration could not be made too high; but unfortunately the E. M. F. increases with the frequency only up to a certain point. Beyond this, other factors appear, with a constantly increasing influence, and prevent a further rise of E. M. F. When this point is reached, the time for the full action of the primary current is cut short, and the E. M. F. cannot increase. The magnetic flux being limited, it follows that the secondary current must be affected in a similar manner, and the increase that should have resulted from the high speed of the moving magnetic field is cut down by the high counter E. M. F. following in its wake. Therefore, if an increase of E. M. F. is looked for, the results are disappointing; but, on the other hand, a material gain is realized in the smooth form of the alternating current. Consequently, in the modern medical coils, the frequency of vibration is pushed as high as 10,000 to 15,000 interruptions per minute, the object in view being rather to procure a current of a peculiar soothing nature, than one of a high E. M. F. A current of this kind can be obtained only by means of a perfect vibrator, the action of which is even, and not of a jerky character. Should, for instance, a spring, while vibrating at a high speed, reduce its

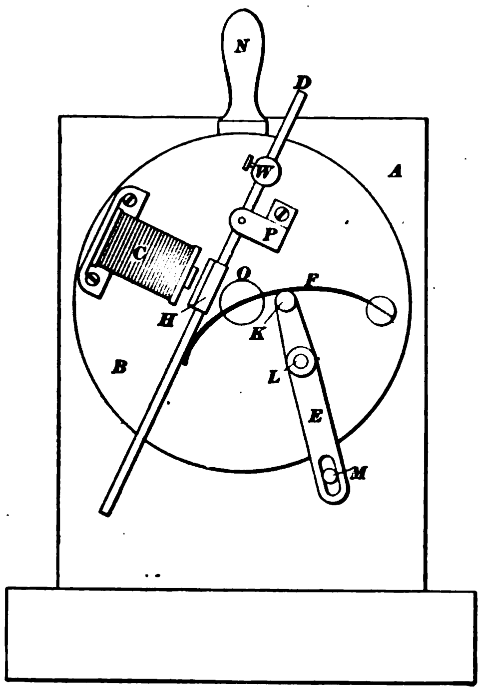


FIG. 72.

speed or stop at certain intervals, then such variation would once be accompanied by a wave of high E. M. F., which would have a decidedly unpleasant effect and spoil the work of an otherwise perfect instrument. For this reason it is important that the action of a vibrator be examined very closely in order to discover whether it is subject to such irregularities.

108. Testing an Induction-Coil.—When examining a coil, first see if its E. M. F. is high enough for the production of what is called high-tension currents. For this purpose a Geissler tube of moderate size, say three to four inches long, is very useful. The terminals of the secondary coil are connected to the Geissler tube by means of two short pieces of copper wire, and, after the room has been darkened, the coil is set in operation. Unless the secondary coil contains at least as much wire as the coil mentioned in the table in Art. **102**, that is, about 2,550 yards of Nos. 21, 32, and 36, no effect will be produced. If the voltage is sufficient, the tube will glow, and its brightness will increase with a rise in E. M. F.

After it has been proved that the coil has sufficient voltage, the Geissler tube may be employed to study more closely the action of the vibrator. The tube will show patches of light of a cup-like form, with a wavy motion. If the motion is uneven and of an intermittent nature, it is proof that the action of the spring is irregular, and that the interrupter must be adjusted until the vibrations are even. These experiments should be repeated with one or more cells until the entire strength of the battery has been employed in the test.

A more delicate and efficient test may be performed by means of an ordinary telephone receiver. It is connected to the coil by the usual conducting-cords, and when placed to the ear will indicate every variation in E. M. F. both in the primary and in the secondary coil. Irregularities in vibratory action that would otherwise pass unobserved would be quickly detected by this method.

The bipolar electrode may also be used for testing the regularity of the vibratory action of the interrupter. After the electrode has been connected to the secondary coil, the tips of two fingers should be placed one on each side of the metal rings. When used with the coils of fine wire, a light touch of the fingers is sufficient to discover irregularities in the current, while for larger currents it is necessary to hold the electrode tightly in one hand.

109. Transformers.—By the term **transformer** is ordinarily understood an apparatus that will transform an electric current of a certain amperage and voltage into another current either of a higher or lower amperage with a corresponding change in voltage. An induction-coil would therefore, in reality,

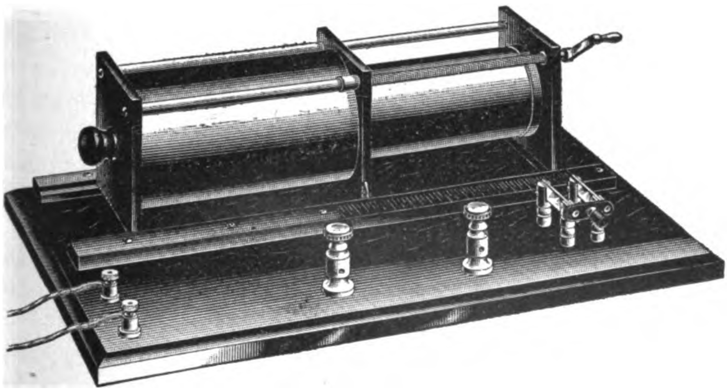


FIG. 73.

have to be classed as a transformer, because it changes a battery current of relatively low voltage and high amperage into a current of high E. M. F., but of small strength. Notwithstanding this similarity, there is a certain difference between them that requires them to be considered separately. This difference consists mainly in the operation of the primary coil. In an induction-coil this is acted on by an intermittent direct current, while the primary coil of the transformer is furnished directly with an alternating current, generally from the commercial lighting circuit. A transformer needs, therefore, no interrupter, and there is this additional distinction between them that, whereas the induction-coil is provided only with an interior core of iron, and the magnetic flux, therefore, has to return through the air; the transformer, on the other hand, is provided, also, with an external casing of laminated iron, thus permitting the magnetic flux to flow entirely through iron, or nearly so.

Some of the transformers used in electrotherapeutics have for practical reasons not been provided with this external casing, as, for instance, the transformer shown in Fig. 73. This is, in reality, nothing but an induction-coil of the Dubois-Reymond type, the only difference being that the primary coil is furnished with an alternating current through the two binding-posts to the left, while the alternating current from the secondary coil is delivered through the two front binding-posts. By turning the little crank at the head of the primary coil the secondary coil can be moved so as to be more or less under the influence of the magnetic field of the primary coil. This will enable the operator to regulate the voltage of the secondary current within very wide limits.

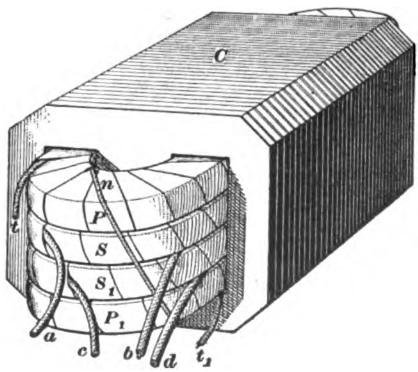


FIG. 74.

The form usually given to the transformer when used for commercial lighting purposes is shown in Fig. 74. C is the iron core that almost entirely encloses the coil. There are four coils, of which P, P_1 form the primary, the two coils being connected in series, as indicated by conductor n. The terminals of the primary are shown at t, t_1. S, S_1 are the two secondary coils, which may be connected either in series or in parallel, as desired, their terminals a, b, c, d being brought out separately for this purpose.

110. Action of the Transformer.—It is unnecessary at this point to give any detailed description as to how an alternating E. M. F. is produced in the secondary coil of a transformer, as the action is almost identically the same as that of the induction-coil. In either case, it is a question of compelling the lines of magnetic force of the primary coil to cut across the secondary and thereby induce an E. M. F. in the latter. In the induction-coil this was attained by starting and stopping the current in the primary coil, while in the transformer similar results are obtained by periodically reversing the current. The results, so far as the character of the secondary current is concerned, are not the same. We saw that from the mode of interrupting the primary current in the induction-coil, the same was more or less one-sided, that is to say, the wave of the breaking current was considerably stronger. Its secondary current would partake of the same characteristics, and under certain conditions the difference between the closing and opening currents would be so great as to practically make the secondary current a unidirectional interrupted current.

In a transformer whose primary coil is supplied with an alternating current of the sinusoidal class, described in *Direct Currents*, the secondary current has an entirely different character.

The rate of variation in the current-strength, both of the positive and negative wave, is very gradual and devoid of any abrupt changes. The result is that the current flowing through the secondary coil will have the same characteristics. The positive and negative waves will both be of the same voltage.

This was obtained to some extent in the sinusoidal alternators, but in small apparatus like these, it is more difficult to obtain the same results as it is by means of the large alternators in the commercial lighting stations, that supply the currents for the primary coils of the transformers.

The currents from the induction-coil and the transformer have, by reason of their different characteristics, each their proper fields for action, and it is to be kept in mind that they cannot in all cases be considered as equally efficient.

111. Use of Transformers.—While the main purpose of the induction-coil was to change a rather large current of low E. M. F. into a small current of high E. M. F., the transformer will not alone do this, but will also change a current of high into one of low E. M. F. Transformers of the first kind are called **step-up transformers,** and when reducing the E. M. F., **step-down transformers.** The ratio of the secondary E. M. F. to the primary E. M. F. is very nearly the same as the ratio of the number of turns in the coils. This ratio is called the **ratio of transformation.**

For ordinary applications, such as for lighting, step-down transformers are used, the usual ratio of transformation being 10:1, so that, with a 1,000-volt primary, the secondary E. M. F. is 100 volts.

The sizes of the primary and the secondary coils, shown in Fig. 74, are very nearly equal, although the number of turns of the one is perhaps 10 times that of the other. The size of the wire used in the secondary coil of this step-down transformer, however, must be so much larger in diameter than that of the primary, that the volume of the two coils will be nearly the same.

It must be kept in mind that no *gain* is made in electric energy by transforming a current to a higher or lower voltage. Theoretically considered, the energy of both the primary or secondary currents should be the same, but a transformation cannot be accomplished without some loss. We find, therefore, that the energy delivered by the secondary coil is smaller than that delivered to the primary.

In *Direct Currents* it was shown that the power W of an electric current was found by means of the formula $W = E \times C$. If, for instance, the current in a primary coil has an E. M. F. of 6 volts and a strength of .5 ampere, its power would be $W = E \times C = 6 \times .5 = 3$ watts. When the secondary coil is so wound as to produce an E. M. F. of 500 volts, the current-strength will be correspondingly reduced. By means of the formula $C = \frac{W}{E}$, we find that C is now .006 ampere = 6 milliamperes and the product $E \times C = 500 \times .006 = 3$ watts, is the same as before. In reality, the secondary coil would suffer a loss in pressure and would deliver a current somewhat smaller than 6 milliamperes, hence would not return all of the 3 watts furnished to the primary coil.

The induction-coil can be considered as a step-up transformer, while the transformer shown in Fig. 74 is an example of a step-down transformer. In electrotherapeutics, step-down transformers are also used when a strong current is demanded for cautery-work. The primary coil is connected with the lighting circuit and a low E. M. F. induced in a secondary coil that is made of thick wire. The latter coil will then deliver a current from 5 to 30 amperes, depending on the position of the secondary coil, relative to the primary. Transformers of this class are described in *Physics of Light and Cautery.*

112. Measurements of Current-Strength. — When an ordinary galvanic current is used for therapeutic purposes, we find, as was shown in previous pages, no difficulty in measuring its quantity and adjusting the latter to any desired amount. This is important with a direct current, because the currents used are often so weak that one would be ignorant of their presence but for the indications of the ammeter. With the alternating current derived from the induction-coil the conditions are entirely different. Here the ordinary ammeter will no longer serve as a measuring instrument because the direction of the current is constantly changing, and changing so rapidly that it is impossible for the moving parts of the instruments to follow these reversals, and they seem to indicate that no current is passing.

There are ammeters and voltmeters that will indicate, respectively, the amperage and voltage of an alternating current, but these do not indicate the absolute, momentary values of the current-strength and voltage, but their *effective* values.

These effective values are found by letting the current expend its energy in heating a given resistance that is devoid of self-induction. The same resistance is then exposed to the heating effect of a direct current E. M. F. and that value of the latter that was required to produce the same effect is taken as the equivalent of the alternating E. M. F. The same procedure is followed when measuring the alternating current. Its rate of flow is constantly changing, but its heating effect may be determined and compared with that of a direct current; we have, then, what is termed the *effective* current-strength.

Instruments able to indicate the current-strength or voltage of an induction-coil current are difficult to make, because dealing with extremely weak currents. They are therefore expensive and require great care in handling, and for these reasons they are rarely used. Fortunately, it is of minor importance to know the effective E. M. F. or amperage of this induced current when used for therapeutic purposes. It is more a question of tolerance, and this will vary with different persons.

To have means for a delicate graduation of the current-strength is of greater importance than to know its real value. Nevertheless, the operator should be able to foretell the general effects of the various combinations that his apparatus will allow, and subsequent minor variations should be made only to suit individual cases. This is done either by means of the method employed in the Dubois-Reymond coil, or by the method described in Art. 103 in conjunction with a rheostat, or by using rheostats both in the primary and secondary circuits. The apparatus required for effecting these current-regulations is fully described in *Accessory Apparatus.*

ELECTROSTATICS AND HIGH-FREQUENCY CURRENTS.

ELECTRIFICATION.

1. Positive and Negative Electricity.—In the previous Sections of this Course we have considered electricity in motion. When an electrification takes place on a substance that is able to conduct electricity, the latter will at once be distributed throughout such a substance and cause a flow, or current. In case the substance is *not* a conductor the various electromotive forces that may have been produced on the substance have no opportunities for equalizing themselves, and the charge will remain where it was produced.

When a body is in this state it is customary to say that it is *positively* or *negatively* electrified, meaning thereby that in the former case a current would flow *from* the body, and in the latter case *into* it, if a conductor were brought in contact with it. This property of a non-conductor by which it is able to retain an E. M. F. in a condition, so to say, dormant, but ready to send a current in one direction or other, depending on whether its potential is positive or negative, has given rise to the idea that there are two kinds of electricity, positive and negative. It is then supposed that ordinarily, when a body is in a neutral condition, these two kinds are mixed, but that after electrification has taken place the positive would separate from the negative and form two distinctive kinds of electricity, different in character and tendency. These two kinds would eagerly seek to unite with each other and again produce a neutral condition.

We are here in the same position as when we were considering the flow of a current. It was then remarked that, if a flow of electricity really took place, we were not certain in which direction it actually was flowing. A current might possibly flow from the body of lower to that of higher potential, or might flow from both simultaneously, or not flow at all. In any case, we preferred to speak of the equalization of different potentials as causing a *current* of electricity, as this made it easier to describe the various phenomena and to formulate rules and laws.

2. The same holds true with the phenomena of static electricity. When two bodies are respectively positively and negatively electrified, there is a mutual action between them, which seems to be similar to that taking place between two magnetized bodies. Moreover, the forces seem here to act along lines of force, and to cause attraction or repulsion, as the case may be; also, we must here suppose the *ether* to be the medium that transmits the forces from one body to the other. Notwithstanding these facts, we prefer to speak of positive and negative electricity, because it makes it much easier to explain the phenomena of static induction and the action of static induction-machines. When, therefore, in the following pages, we speak of positive and negative charges, it must not be taken for granted that such charges actually exist, but that on the contrary these terms are simply used for convenience, as, without them, it would be almost impossible to describe the phenomena of static electricity to one not familiar with the science of electricity.

3. Charge.—When a body has been submitted to some influence that has changed its neutral condition into one in which a difference of potential has been created, either between different parts of the same body or between different bodies, the body is said to have been electrified, or to have been **charged.**

The one part or body that possesses a positive potential is said to be positively charged; the other, negatively. *It is impossible to bring forth one charge without bringing forth another of equal quantity.*

4. Conductors and Insulators.—If an electric charge is communicated to one end of a glass rod it will remain there, and will not pass to the other end of the rod. The glass rod will not permit the charge to spread through its substance, because it is a non-conductor, or what is called an **insulator.**

If, on the other hand, a metal rod receives an electric charge at one end, the charge will immediately distribute itself over the whole rod. The metal rod, unlike the glass rod, *conducts* the charge from one portion of its surface to all other portions, and is therefore called a **conductor.** A substance that is an insulator is said to offer a great *resistance* to the flow of electricity through it, but it must not be supposed that conductors offer no resistance. The fact is, there is no substance so good an insulator as not to allow some electricity to pass, and there is no conductor that does not possess some resistance; no sharp distinction can be drawn.

In the following list various substances are placed in the order of their conductivity.

Good Conductors
- Silver
- Copper
- Other metals
- Charcoal
- Water
- The human body, except the epidermis

Semiconductors
- Cotton
- Dry wood
- Marble
- Paper
- Alcohol
- Ether
- Powdered glass
- Ice at 32° F.

Non-Conductors, or Insulators
- Oils
- Porcelain
- Wool
- Silk
- Resin
- Gutta-percha
- Shellac
- Paraffin
- Glass
- Dry air

FRICTIONAL ELECTRICITY.

5. Both Bodies Conductors.—The means employed for electrifying bodies depends somewhat on their nature—whether they are conductors or non-conductors. In the case of two conductors, by merely bringing them in contact a positive charge is produced on one and a negative charge on the other. The amount of charge so obtained may, however, be very slight, and requires delicate measuring instruments to detect it.

6. One or Both Bodies Insulators.—When one or both of the bodies are insulators, or non-conductors, it is necessary that one of them be brought in energetic contact with the whole surface of the other, or as much of it as is to be electrified. This is usually done by rubbing one body intimately with the other, as, for instance, a silk handkerchief with a glass rod, or a piece of cat's fur with a stick of sealing-wax. When the bodies are separated, after rubbing, each will be found to be charged—one positively, the other negatively. The friction between the two substances simply causes contact between their various parts, and the charge should therefore be considered of the same nature as that generated by contact between two conductors. The difference between the two cases is that, in the case of the conductors, the charge flows to all parts of the body, while, in the case of the non-conductors, the various parts have to be charged separately by contact.

7. Energy of Charge.—The amount of electric energy stored up on either of the bodies is not proportional to the work done by friction, but only to the small work done in separating the two bodies against their mutual attraction.

8. Conditions for Electrification.—It was formerly thought that only a limited number of substances could produce an electric charge when brought in contact with each other; but later investigations show that friction between any two different substances, no matter what the substances may be, always produces a separation of positive and negative electricity. It is not even necessary that the substances should be different, as two bodies of the same substance, one with a smooth and the other with a rough surface, will show a charge when rubbed together. In this instance, the body whose particles are more easily removed shows negative electricity. Two bodies of the same substance with different temperatures will show electrification, and it has also been shown that two bodies of the same substance, but of different colors, will in some cases be electrified when rubbed together. Whether the bodies are brought in contact by means of either rolling or sliding friction seems immaterial. The main thing seems to be to bring the various parts of the surface of one body successively in contact with the surface of a dissimilar body, and separate them, in order to produce a charge. Static electrical machines are based on these principles, and the following experiments, some of which may appear quite elementary, are made for the purpose of making the action of electrical machines, belonging to either the friction or the induction system, perfectly clear.

9. Conditions Governing Kind of Charge.—Let us now consider the conditions necessary for producing an electric charge on a body, and the means of detecting its presence and kind. Evidently this latter feature is a very important one, as all of these phenomena can be studied only by the most careful use of the testing instruments, both as regards the correct interpretation of the action taking place, and also in preventing exterior forces from interfering with the forces under observation.

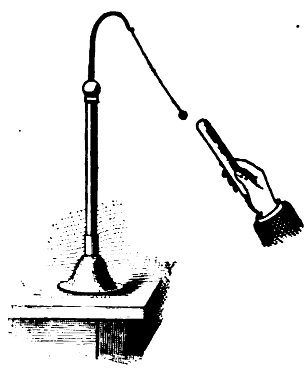


FIG. 1.

By rubbing a glass rod with a piece of silk, the rod will receive a charge that it has been agreed to call *positive;* the charge on the silk will, therefore, be *negative.* The presence of the charge can be detected by holding the glass rod in the neighborhood of light bodies, such as chaff or small bits of paper; it is seen that these small particles are attracted by the rod, and, after contact with it, partake of its charge and are repelled.

10. The Electric Pendulum.—A more suitable apparatus for studying these actions is an **electric pendulum,** as represented in Fig. 1. It consists of a glass rod supporting a metal bracket, which carries a silk thread to which is attached a pith-ball. If the glass rod is held near the ball, it will be attracted by the rod, and then, having partaken of its charge, be repelled. Now, by rubbing a stick of sealing-wax with a piece of fur, a charge will be given to the stick, and if it is held near another pith-ball, the ball will also be attracted, and after contact repelled. As these two rods have the same effect on two separate pith-balls, it would naturally be supposed that they would be charged with the same kind of electricity; but let us now see the effect of holding the sealing-wax near the pith-ball repelled by the glass rod. It will be attracted, and after contact repelled, and the same will take place if the glass rod is held near the other ball. Evidently the two charges must be of a different nature, and, if the glass rod is *positive*, the sealing-wax must be *negative*.

As another experiment, touch one of the balls with the charged glass, and the other with the charged sealing-wax. Now bring the two balls into proximity; it will be found that there is an attraction between them. Again, charge both balls from the glass rod, or both from the sealing-wax; in each case the balls will repel each other.

11. It was stated that two substances rubbed together will have different charges, so that, when the glass rod is positive, the silk should be negative. The pendulum will prove this, because, after the ball has been attracted and repelled by the glass rod, it will be attracted anew by the silk. If, again, the electricities of these two bodies is imparted to a third body, the latter will have no effect on the pendulum, proving that both electric charges have united and neutralized each other.

We deduct from these experiments the following laws:

1. *When two dissimilar substances are placed in contact, one of them always assumes the positive and the other the negative charge.*

2. *Electrified bodies with similar charges are mutually repellent, while electrified bodies with dissimilar charges are mutually attractive.*

These are two of the most important laws in the study of electricity.

12. The Electric Series.—As has already been stated, glass rubbed with silk will receive a positive charge. Such a charge was formerly called *vitreous*, under the erroneous impression that this was the only kind of charge glass was capable of yielding. It is found, however, and can be easily proved by the electric pendulum, that glass rubbed with fur will receive a negative charge. Sealing-wax or resin rubbed with silk will, as has been pointed out, take a negative charge, and for this reason a charge so obtained was called *resinous* electricity. If, however, wax or resin is rubbed with gutta-percha, the former will take a positive charge, proving that these substances are capable of receiving either a positive or a negative charge. It will thus be seen that the character of the charge depends equally on the material composing the two substances rubbed together.

The following list, called the **electric series,** gives the various substances in such an order that each receives a *positive* charge when rubbed with any of the bodies following, and a *negative* charge when rubbed with any of those which precede it:

1. Fur	6. Cotton	11. Sealing-wax
2. Flannel	7. Silk	12. Resin
3. Ivory	8. The human body	13. Sulfur
4. Crystal	9. Wood	14. Gutta-percha
5. Glass	10. Metals	15. Guncotton

13. Charges on two bodies may differ not only in kind, but also in amount. If a charged body is brought in contact with a larger body not charged, or charged with the opposite kind of electricity, there will be a redistribution between the two bodies. If the charges are equal and opposite, no charge will remain on either. If the charges are of opposite kind and unequal, then the smaller will be neutralized by an equal amount of the larger, and the remainder of the larger charge will distribute itself over the surfaces of both bodies. The speed with which this distribution takes place depends on the substance of the body; if a good conductor, it will be practically instantaneous; if an insulator, it will be slow, and will take appreciable time.

MEASUREMENT OF CHARGE.

14. The Gold-Leaf Electroscope.—For very crude tests, the electric pendulum may be sufficiently accurate, but, when finer measurements are needed, an instrument will be required that is capable of indicating minute charges, and at the same time is shielded from the moisture and motion of air. Such an instrument is the **gold-leaf electroscope**, illustrated in Fig. 2.

A brass wire *x*, the lower end of which is bent so as to support the two gold leaves *a*, is passed through a glass tube *b*, projecting through a well-varnished cork closing the mouth of a glass jar *J*. The upper part of the brass wire is provided with a flat disk, or plate *c*, of conducting material. This instrument not only shows whether a body is electrified or not, but can also be made to show the kind of electricity with which a body is charged.

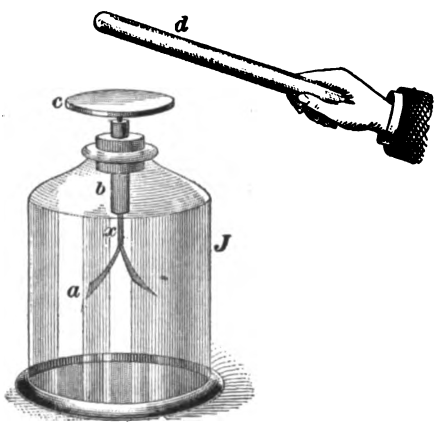


FIG. 2.

Let us rub a glass rod *d* with silk, and hold it in the neighborhood of the disk *c*, without making actual contact. The gold leaves will diverge. The glass rod we know to be positively electrified, and, when it is brought near to the disk *c*, a separation of the electric fluid in the metallic portions of the electroscope takes place, the negative electricity being attracted to the plate *c* by the positive charge on the glass rod *d*, and the positive charge being repelled to the gold leaves. This charges the two gold leaves positively, and, as similarly-charged bodies are mutually repellent, they are caused to diverge. If the rod is withdrawn without touching the plate *c*, the positive and negative charges on the electroscope reunite, thus allowing the gold leaves to come together. The action described, causing a separation of the two electricities in a body by the proximity of a charged body, is called *induction*, and is treated at greater length in Arts. **20**, *et seq.*

Again bring the rod near the electroscope, and this time touch the plate *c*. On removing the rod the leaves remain diverged, because some of the charge on the rod is imparted to the electroscope. This charge is of course positive, and causes the gold leaves to remain diverged until the charge is removed. Knowing the character of this charge, we are able to compare other charges with it and find out whether they are of the same or of a different kind.

Let the glass rod be rubbed with flannel. The question now to be answered is whether the rod is charged with positive or with negative electricity. On bringing it near to the disk on the electroscope, the leaves show a tendency to close together. This is evidently because there is less repulsion between them; that is, their positive charge must have become less. Evidently, then, the rod must be negatively charged, so that it attracts a part of the positive charge on the leaves towards it, leaving them less strongly charged. On the other hand, if the rod were positively charged, the gold leaves would spread wider apart, because the positive charge on them would be made stronger.

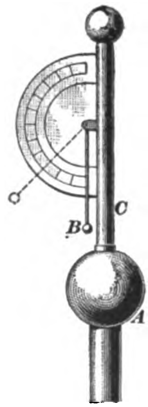


FIG. 3.

From the foregoing we may draw these conclusions:

If the gold leaves diverge, the body being tested has a charge of the same kind as that on the electroscope. If the gold leaves approach each other, the charge is of the opposite kind.

15. Quadrant-Electroscope.—When it is desired to indicate and measure very large charges, an instrument called the **quadrant-electroscope,** shown in Fig. 3, is used. *A* is a conductor on which the charge to be measured is placed. It is provided with an upright rod *C* on which the electroscope is mounted. *B* is a pith-ball, supported by a light arm pivoted on the upright rod. When the conductor *A* is charged, the ball will be repelled in proportion to the charge, and a graduated scale will indicate the angle of divergence.

16. Torsion-Balance.—Both in the electric pendulum and in the electroscope, we have seen forces at work repelling similarly-charged bodies. The magnitudes of these forces under varying conditions are as yet unknown to us, and it is desirable to examine them a little closer. None of the instruments so far mentioned will do this with any accuracy, and some other means must be provided. This we find in the **torsion-balance**, a combination of an electric pendulum and an electroscope. In Fig. 4 a light arm of shellac is provided with a gilt pith-ball *n* suspended from the movable head *b* by means of a fine silver wire. Another gilt pith-ball *m* is fastened to the end of a glass rod *a*, which can be inserted through an opening in the cover of the glass cylinder. Around the cylinder, on a level with the pith-balls, is a graduated circle. The head *b* is called the *torsion-head*, and is also graduated, and its angular motion is indicated by means of an index on a fixed arm near it.

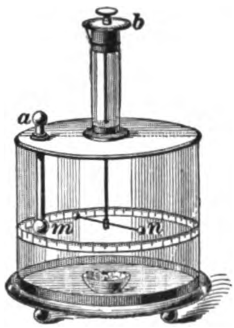


FIG. 4.

To measure the amount of an electric charge, we proceed as follows: The torsion-head is turned until the balls just touch each other; the glass rod is removed and a charge imparted to the ball *m*, and the rod is then replaced. As *n* is uncharged, it will receive part of the charge on *m*, and the two balls will mutually repel each other; *n* will recede and produce a certain twist in the silver wire. When the repelling force is counterbalanced by the twisting force, the arm will come to rest. As the angle through which a wire is twisted is precisely proportional to the force with which it is twisted, it follows that the force of torsion is proportional to the angle of torsion. If the angle through which the ball moves is not too large, the ball will practically move in a straight line, and it may therefore be said that the force of torsion is proportional to the direct distance between the balls.

17. Law of Inverse Squares.—By means of the torsion-balance it is possible to prove that *the force exerted between two small bodies, statically charged with electricity, varies inversely as the square of the distance between them.* Thus, if two electrified bodies, 2 inches apart, repel each other with a certain force, this force will be four times greater if the distance between them is decreased to 1 inch. This law holds good for both repulsion and attraction, and also when the charges on the two bodies are of unequal amounts. At a given distance, the attraction or repulsion between two bodies will be *proportional to the product of the two quantities* of electricity with which they are charged. For instance, if one body is charged with 5 units, and another with 3 units of electricity, the force acting between them will be $5 \times 3 = 15$ times greater than it would be if each body had received but 1 unit.

18. Unit Quantity.—A unit quantity of electricity is that charge which, when placed in air at a distance of 1 *centimeter* from another equal and similar charge, will be repelled with a force of 1 dyne. The **dyne**, or unit of force, is that force which, by acting on a mass of 1 gram for 1 second, can give to it a velocity of 1 centimeter per second.

19. The Coulomb.—There is another unit of quantity based on what is called the electromagnetic system of units. This is called the **coulomb**, and its value is 3,000,000,000 times that of the electrostatic unit.

ELECTROSTATIC INDUCTION.

20. We have seen that, when electricity has been transferred from one body to another by actual contact, an attraction or repulsion will take place; but we have also seen, when mention was made of the gold-leaf electroscope, how a charge could be present on the gold leaves when no actual contact had been made with charged bodies. This latter phenomenon is perhaps the most important one in static electricity, and deserves a great deal of attention.

21. The Electrostatic Field.—It is accepted as a matter of fact that an electrified body can have no influence on a body not charged with electricity. How, then, can we explain why a neutral pith-ball is attracted by a rubbed glass rod? The answer is that, before any attraction takes place, the glass rod has, while some distance away, caused a division of the neutral state of the ball into positive and negative electrification, so that a negative charge has collected on the side next to the glass rod, and has therefore been attracted. All this will take place almost instantaneously, but, before the positive and negative charges have been established, no attraction will be noticed. This influence, which a charged body is capable of exerting on a neutral conductor, is called **induction,** and the charge is called an *induced* charge. The range of space in which it takes place is an *electrostatic field.* We recognize here conditions very similar to those explained under magnetic induction.

22. The apparatus shown in Fig. 5 illustrates this phenomenon more fully. C may be a glass ball charged with positive electricity, and $A\ B$ a conductor with no charge, both insulated from the ground by glass columns. When C is placed in the neighborhood of $A\ B$, electric charges are induced on the conductor, and it is found that its two ends have charges of opposite kinds. The pith-balls suspended from the conductor will also show that the charges are not uniform, because the former are seen to diverge more and more, the farther they are from the center of the conductor; in fact, the middle part will show no charge whatever. It is also found, by testing with an electroscope, that the end A is charged with negative and the end B with positive electricity. Should the ball C again be removed, we see that the pith-balls touch each other; the charges have, therefore, entirely disappeared. They have neutralized each other, and therefore must originally have been present in equal amounts. The conductor may be made in two parts and separated before the ball C has moved away, in which case each part will have a charge of an opposite kind.

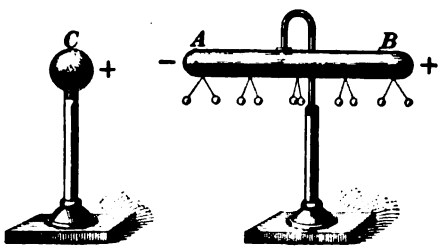


FIG. 5.

From this experiment we draw the conclusions that a positive charge attracts a negative charge and repels a positive one, and vice versa, and that this influence can take place through some distance and through materials such as air, glass, etc.; that, when the electrified body is removed, it will again return to its natural condition, and that the inducing body has lost none of its charge.

If the body on which the charge is induced has connection with the ground, the results are somewhat different. Let the bodies occupy the position illustrated in Fig. 5. If, now, a connection is established between *A B* and the ground by touching it anywhere along its surface, even at *A*, the positive charge will escape and be neutralized in the ground, and the negative charge only will remain. The charge that passed to the earth is called a *free* charge, while that charge which is held by the inductive influence of *C* is called a *bound* charge. On the removal of *C*, the induced negative charge is released; it is also *free*, and will now distribute itself over the whole surface of the conductor.

23. There is yet another modification of these experiments to be considered. The smaller the distance between the two bodies, the stronger the induced charge will be; it would eventually be equal to that on the charged body. Before this position could be reached, however, the insulating capacity of the intervening substance (in this instance air) would break down, and the charges rush across and reunite with such avidity that a spark would be seen between the bodies. The negative charge at *A* and the positive at *C* have now reunited, and have by that act neutralized each other. The bound charge at *B* is now free, and positive electricity is distributed all over *A B*.

In the latter experiment, the induced negative charge was supposed to be of equal quantity with the inducing positive charge; by their union they would therefore neutralize each other. Should the charges on two bodies not be of equal amount, there will remain, when they combine, a surplus of a kind depending on which charge predominated. Thus, if one body is charged with 50 units of positive and another with 30 units of negative electricity, their union will result in the neutralization of 30 units of each charge, leaving 50 — 30 = 20 units of positive electricity ; and this quantity will divide itself, giving each body a positive charge of 10 units, provided the bodies are of equal size and of the same shape.

24. Inductive Capacity.—It is not unimportant what substance is residing between two charged bodies, as some substances permit the induction to take place with greater facility

Material.	Inductive Capacity.
Air, vacuum at about .001 millimeter pressure	.9400
Air, vacuum at about 5 millimeter pressure	.9990
Hydrogen, at ordinary pressure	.9990
Air, at ordinary pressure	1.0000
Carbon dioxid, at ordinary pressure	1.0005
Olefiant gas, at ordinary pressure	1.0007
Sulfur dioxid, at ordinary pressure	1.0037
Paraffin, clear	1.92–2.47
Petroleum	2.03–2.07
Turpentine	2.16
India-rubber, pure	2.34
India-rubber, vulcanized	2.94
Resin	2.55
Ebonite	2.56–3.15
Sulfur	2.88–3.84
Shellac	2.95–3.73
Gutta-percha	4.20
Mica	5.00
Flint glass, very light	6.57
Flint glass, light	6.85
Flint glass, very dense	7.40
Flint glass, double extra dense	10.10

than others. *Dry air offers more resistance to induction than any other substance.* The facility with which a substance allows electrostatic induction to take place across it is called its *inductive capacity*, and the substance itself is called a *dielectric*. An insulator and a dielectric are not necessarily the same thing ; a good insulator may be a poor dielectric, but all dielectrics are insulators. There is this distinction between them, that the *more* resistance a substance offers to the passage of an electric current, the *better insulator* it is, while the *less* resistance a substance presents to an inductive influence across it, the better *dielectric* it is said to be. A good dielectric is said to possess a *high* inductive capacity.

The preceding table gives the inductive capacity of various substances, the capacity of air at ordinary atmospheric pressure being taken as unity.

25. The Electrophorus.—The amount of electrification that can be produced by rubbing a glass rod is rather limited, and, in order to produce larger charges on other bodies, the use

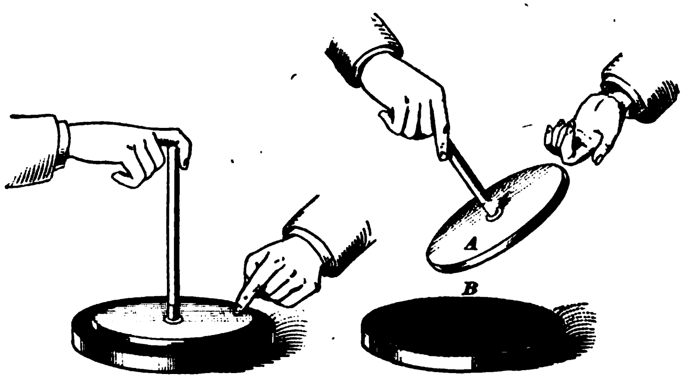


FIG. 6.

of some other apparatus becomes necessary. This is found in what is called an **electrophorus.** By means of this instrument an almost unlimited number of static charges of electricity may be obtained from one single inducing charge. It consists of two main parts (Fig. 6), one a round cake of resinous material cast in a dish, or pan *B*, about 1 foot in diameter; and a disk *A*, slightly smaller, made of metal, or of other material, covered with a conducting substance, and provided with a glass handle. In modern instruments, *B* is usually made of ebonite. When using the electrophorus, the resinous cake must first be beaten or rubbed with a warm piece of woolen cloth or fur. The disk, or cover, is then placed upon the cake, touched momentarily with the finger to liberate the free charge, then removed by taking it up by the handle. It is now found to be powerfully electrified with a positive charge, so much so, indeed, as to yield a considerable spark when the hand is brought near it. The cover may be replaced, touched, and again removed, and will thus yield any number of sparks, the original charge on the resinous plate meanwhile remaining as strong as ever.

If the previous experiments in induction have been well understood, it should not be difficult to see the reason for these phenomena, and, as they serve as a basis for electrostatic machines, it is important that they appear perfectly clear before we proceed any further.

After the cake has been beaten with the fur, its condition is that of Fig. 7; it is charged with negative electricity. When the disk A is approaching the cake, the latter will act inductively on the disk, and attract a positive charge on its lower side and repel a negative charge to its upper side. These charges will increase in amount until they reach a maximum, when

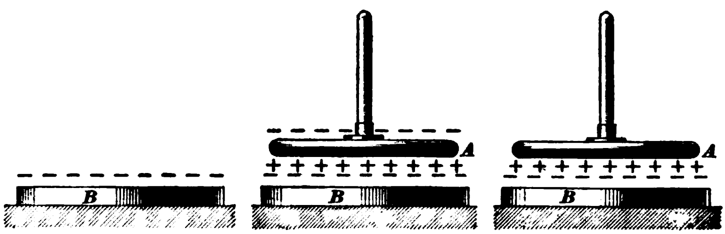


FIG. 7. FIG. 8. FIG. 9.

contact is made with the cake. This condition of cake and disk is represented in Fig. 8. Should the disk be now touched, the free negative charge will be neutralized by electricity flowing through the observer's body to earth, while the positive electricity will remain as a bound charge, as shown in Fig. 9. The disk can now be lifted, when the positive charge will be no longer bound, and will distribute itself all over the disk, as illustrated in Fig. 10.

The charges given to the disk will not diminish the original charge on the cake, as the action is purely inductive, and the recharging of the former could go on forever if the cake were not subjected to a certain amount of leakage through the atmosphere, particularly when the air is damp. The charge must therefore be replenished at certain intervals. If a metallic stud is fastened to the bottom of the pan B, so as to project through the cake near its surface, a spark will pass between the stud and the lower side of the disk when this is laid down on the cake, and the negative electricity will be automatically discharged, thus dispensing with the necessity of touching the disk before removal.

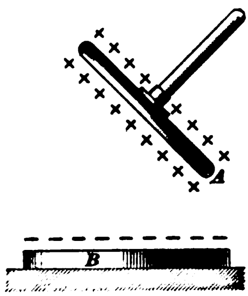


FIG. 10.

It was remarked above that, were it not for the leakage from the cake through the air, the charging and discharging of the disk could go on indefinitely. Evidently, the supply of energy represented by each charge must be drawn from some source, and it is of some interest to inquire into its origin. The fact is that, when the disk is removed from the cake, after being charged, it offers more resistance against its removal than when it was neutral. This supply of muscular energy is the real measure of the energy dissipated in each discharge of the disk.

POTENTIAL.

26. Change of Potential.—The experiments with the electrophorus do not exhaust all the possibilities of inducing charges in neighboring bodies, and it will be necessary to consider some further modifications. These can best be observed by means of the two disks shown in Figs. 11, 12, and 13, where A is a metal plate insulated from the ground, and B another metal plate provided with a glass handle.

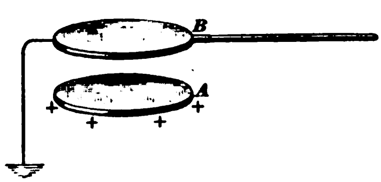


FIG. 11.

Let it be understood that, when mention is made in the following of positive or negative potential, it will mean the potential of the *free* charge on a body subject to induction, a charge that would flow to earth if opportunity were given it.

The various combinations and modifications will be found in the following table, with the resulting potential, density, and charge, the number in the table corresponding to the numbers of the following divisions :

1. Let *A*, Fig. 11, be charged with positive electricity and be without any connection with the ground.

2. A neutral disk *B* in metallic connection with the ground is brought near *A* in the position shown in Fig. 11 ; the positive charge is drawn towards *B* away from the lower side of *A*.

3. Let *B* be brought still nearer to *A*, and more charge will be drawn towards *B*, decreasing the density on the *lower* side still more.

4. If now *A* and *B* are separated again, the condition of both will be as it was before.

5. Now let *B* also be *positively* charged and placed in the position of Fig. 12, without connection with the ground. The

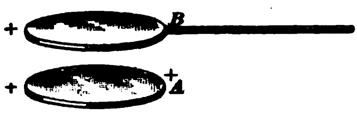


FIG. 12.

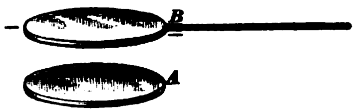


FIG. 13.

density on the *lower* side of *A* is increased ; the charge is, so to speak, driven away from the upper side.

6. Let *B* be brought still nearer to *A*, and the charge on the lower side will increase.

7. While *B* is in the last position, let *A* be connected with the ground ; its positive charge will escape, it will have a bound negative charge, and the potential will be zero.

8. Disconnect *A* from the ground and remove *B* ; the negative charge will be free and spread itself all over *A*, and there will be a negative potential.

9. Next let *A* be *neutral* and insulated from the ground, and *B*, a negatively-charged body, as shown in Fig. 13. Then the potential of *A* will be negative, because negative electricity would escape to the ground if it were connected with it. The density on the upper side is positive ; on the lower, negative.

10. Without changing the position of either body, let *A* be

connected with the ground, when its potential will be zero and its charge positive.

11. Disconnect A from the ground, and separate A and B slightly; the potential of A is then positive.

12. Let B come nearer to A than it did in position 10; then the potential of A becomes negative, because negative electricity would escape from A if connected with the ground, but the charge is positive, as before.

The conditions of conductor A during these experiments are shown in the following table:

CONDITION OF CONDUCTOR A.

		Density.		
Number.	Potential.	Upper Side.	Lower Side.	Charge.
1	Positive	Positive	Positive	Positive
2	Positive, but less than in 1	Positive, but greater than in 1	Positive, but less than in 1	Positive
3	Positive, but small	Positive, and still greater than in 1	Positive, but less than in 1	Positive
4	Positive	Positive	Positive	Positive
5	Positive, but greater than in 1	Positive, but less than in 1	Positive, but greater than in 1	Positive
6	Positive, and still greater than in 5	Almost none	Positive, and still greater than in 5	Positive
7	Zero	Negative	None	Negative
8	Negative	Negative, but less than 7	Negative	Negative
9	Negative	Positive	Negative	None
10	Zero	Positive, and greater than 9	None	Positive
11	Positive, but small	Positive, but less than 10	Positive, but small	Positive
12	Negative, but small	Positive, but greater than 10	Negative, but small	Positive

27. We see, from the interesting phenomena in Nos. 10, 11, and 12, that, by a small motion of B either to or fro, the potential of A is changed from zero to either positive or negative. To make this still clearer, let us repeat the last experiments on the electroscope in Fig. 14.

Let B be given a negative charge and A be neutral; when B is separated from A by a distance d, connect A for a moment with the ground and again insulate it. The negative charge will then have escaped and the potential is zero; the gold leaves will therefore not diverge. Remove B to a distance a little greater than d, and the gold leaves will diverge with positive electricity, because the potential of A is now positive.

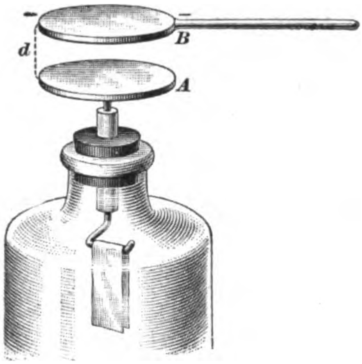


FIG. 14.

Bring B a little nearer than d, and the gold leaves will close and immediately diverge again with negative electricity; the potential is now negative.

28. Conditions Governing Potential.—From these experiments we have seen the influence of the electric charge on the potential of a conductor, and it has been noticed that the potential depends on the sign and amount of the free charge. The experiments, particularly the last three, have also demonstrated that the potential of a conductor depends on its position in relation to other bodies.

It now remains to investigate the influence the shape of a conductor has on its potential. To do this we will again use the apparatus in Fig. 14. Let B be laid on A and a charge given to them while in contact; they will then act as one conductor, and the gold leaves will diverge in proportion to the charge given them. It is now found that, on sliding B on A, or lifting one side of B without separating them, the divergence of the gold leaves will decrease. On putting B back into its original position, the divergence of the gold leaves regains its original value, proving that the alteration of the form of the compound body A B alters its potential without altering the amount of electricity on it.

From all this we finally draw the conclusion that the *potential* of a *conductor* can be varied (1) *by altering the charge of electricity on it;* (2) *by altering the external shape of the conductor without altering the charge of electricity on it;* and (3) *by altering its position relative to other bodies.*

29. Location of Charge.—The preceding experiments also make it clear that the *electricity at rest* resides only on the surface of a conductor, and, so long as we have to do with electricity at *rest*, it is immaterial whether the conductors are of solid or of hollow metal, or whether they are simply made of wood and coated with tin-foil or gold-leaf. It may be well to give some additional proof of this assertion, which may be done in several ways.

Let, for instance, a hollow metal ball with an aperture at the top be supported on an insulating stem and a charge given to the ball. In order to examine the density of the charge on various parts of the conductor, use is made of what is called **a proof-plane,** a little disk of sheet copper fixed to the end of a glass rod. If this disk is laid on the surface of an electrified body, part of the electricity flows into it, when it may be removed and its charge examined with an electroscope. Such a proof-plane, if applied to the surface of an electrified ball and then brought in contact with the knob of an electroscope, will cause a divergence of the gold leaves, showing the presence of a charge. If, now, the proof-plane is inserted through the aperture and touched against the inside of the globe and then withdrawn, it will be found that the inside shows no sign of electricity. Even a cylinder made of wires interwoven with one another will show no sign of electricity on the inside, if the meshes are not too large.

If two hollow hemispheres of copper are placed together over a charged copper ball without touching it, the inner ball will retain its charge only so long as it is not touched, but when it is touched the charge will instantly pass to the exterior ball, and the inner ball is, on removal of the outer, found to be completely discharged. This tendency of a charge to rest only on the outside was shown in a most striking way by Faraday. A conical bag of linen gauze was supported upon an insulating stand, and a silk string attached to its apex by means of which it could be turned inside out. When charged, the electricity was found to reside on the outside, and, when the bag was turned inside out, the charge was again on the outside, leaving the inside without a trace of electricity.

30. Exceptions.—There are a few exceptions to the law that electricity always rests on the outside of a conductor.

1. The presence of an electrified body inside a hollow conductor acts inductively on the latter, and attracts an opposite kind of electricity to the inside of the conductor.

2. Electricity in *motion* does not flow on the surface only, but through the substance of the conductor. This law is therefore limited to an electric charge only.

In medical practice, physicians employ a type of electrical apparatus called *static* machine, which supplies electric charges of very high pressure. As long as these charges can be maintained at rest and separate, they follow the laws of electrostatics. But when they are allowed to unite, an electric current will be produced that will follow the same laws as any other electric current. In electrotherapeutics, the charges are always allowed to unite, whether intentionally or not. If the attempt should be made to keep them separate, such separation could not be maintained by reason of the high pressure of the charges and the chances for leakage. Consequently, we have no longer to deal with electricity at rest, or static electricity, but with electricity in motion, that is, with an electric current.

Much confusion has been caused by the idea that static electricity always remains static electricity, no matter whether it is in motion or not, and that in either case it is electricity of a kind different from that in an ordinary electric current, and therefore subject to different laws. Static electricity as employed in electrotherapeutics has no medical value while at rest. Moreover, no one can prove that electricity resides only on the surface of a patient's body during any form of actual treatment, while every evidence tends to prove that the internal tissues are affected and traversed by the current.

The first exception may be proved by the following experiment: *A* in Fig. 15 is a hollow conductor, in metallic connection with the electroscope *B*; *C* is a metallic ball with a positive charge. When the ball is lowered into *A*, a negative charge is attracted to the inside of the conductor and a positive charge repelled to the outside. The gold leaves will diverge more and more with a positive charge, until the ball is well inside the conductor, when they remain stationary. If contact is now made between the ball and the inside of the conductor, no

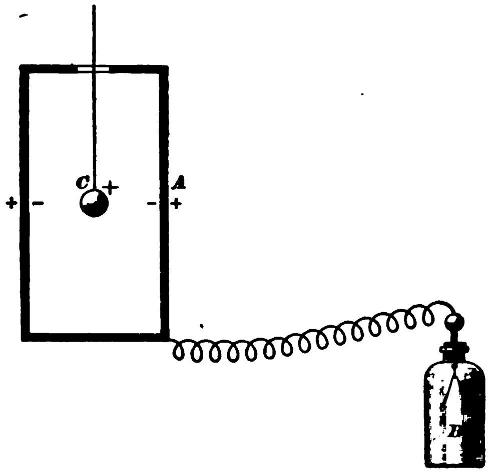


FIG. 15.

effect will be noticed on the gold leaves, which proves that the charge on the inside of the conductor and that on the ball are precisely equal in amount, but of opposite signs; when united they will therefore neutralize each other, and leave the positive charge on the outside, as before. This hollow conductor, or *electric cage*, as it is sometimes called, affords a very ready means for comparing and examining charges on small bodies. They need not be discharged, but simply lowered into the cage; and the induced charge repelled to the outside will be of the same sign and quantity as the inducing charge, and can therefore readily be examined by means of the electroscope.

31. Distribution of Charge.—A static charge of electricity is not usually distributed uniformly over the surface of conducting bodies. Experiments show that there is more electricity on the edges and corners of bodies than on the flatter parts. A charged sphere, if not exposed to the inductive influence of any surrounding bodies, will have the electricity evenly distributed all over its surface; that is, its density is uniform. The density on two similarly-charged spheres in contact with each other is found to be a maximum at the parts farthest from the point of contact, and a minimum in its neighborhood. If the spheres are of unequal sizes, the charges being equal, the density is greater on the smaller sphere; in fact, a decrease in the radius of curvature increases the density until, when at last the radius is so small as to practically be a point, the density has increased to such an amount as to be able to electrify the neighboring particles of air, which are then repelled, each carrying away part of the charge with it, thus contributing to a constant loss of charge. For this reason, points are used when it is desired to secure a rapid discharge, but must be avoided on all parts of electric machinery where a charge is to remain constant.

CAPACITY OF CONDUCTORS.

32. Capacity.—The electrostatic *capacity* of a conductor is measured by the *quantity of electricity that can be imparted to it before its potential is raised from zero to unity.*

To make the meaning of electrostatic capacity clearer, let us consider the capacity of a rubber bag when it is filled with water or gas. Its cubic contents is not limited to one definite quantity; on the contrary, it can vary between wide limits, depending on the pressure to which the water or gas is subjected. By pumping more gas into the bag, under an increasing pressure, the capacity of the bag will increase and also the pressure of the gas contained in it.

A charge of electricity will act in a similar manner. The number of coulombs residing on the surface of a conductor must not be considered as a fixed quantity, depending on the extent of its surface. It is, as seen in the case of the rubber bag, also dependent on the pressure; the higher the latter, the more compressed or dense the charge may be said to be. The smaller the above-mentioned bag is, the less quantity of gas will be required to raise the pressure; similarly with an electric conductor, the pressure will increase more rapidly if its capacity is small. A small conductor, such as an insulated sphere of the size of a pea, will not want so much as 1 unit of electricity to raise its potential from 0 to 1, and is therefore of small capacity; while a large sphere will require a large quantity to raise its potential to the same degree, and could therefore be said to be of large capacity. It is, then, necessary to know both the capacity of a conductor and the potential of the charge before any idea can be had of the quantity of electricity collected on a given conductor.

UNIT OF CAPACITY.

33. The Farad.—If it is necessary to charge a conductor with 1 coulomb of electricity in order to produce a potential of 1 volt, it is of unit capacity, and this unit is called a **farad.** When the quantity is given in *coulombs* and the potential in *volts*, the capacity in *farads* $= \frac{\text{coulombs}}{\text{volts}}$.

EXAMPLE.—If a charge of 200 coulombs increases the potential of a conductor to 50 volts, what is the capacity of the conductor?

SOLUTION.— $\frac{200}{50} = 4$ farads. Ans.

Microfarad.—As the farad is too large for ordinary purposes, it is customary to use only one-millionth part of it, which is called a **microfarad.**

CONDENSERS.

34. Action of a Condenser.—It has been shown that opposite charges attract and hold each other; that electricity cannot flow through glass, and yet can act across it by induction. We have also seen that two pith-balls, one electrified positively and the other negatively, will attract each other across the intervening air. After interposing a plate of glass, they will still attract each other, although the electric charges on them cannot pass through the glass.

If a piece of tin-foil is fastened upon the middle of each face of a thin piece of glass, and one of the pieces is electrified with a positive charge and the other with a negative charge, the two charges will attract each other; that is to say, they are not residing on the tin-foil as *free* charges, for it will be found that on touching either of the foils practically no discharge will take place. We must therefore conclude that each charge is inducing the other—that they are *bound*. It will be found that these two plates of tin-foil may be made to receive a much greater charge in this manner than either of them could possibly receive if placed on the glass alone and then electrified. In other words, *the capacity of a conductor is greatly increased when it is placed near a conductor electrified with the opposite kind of charge.*

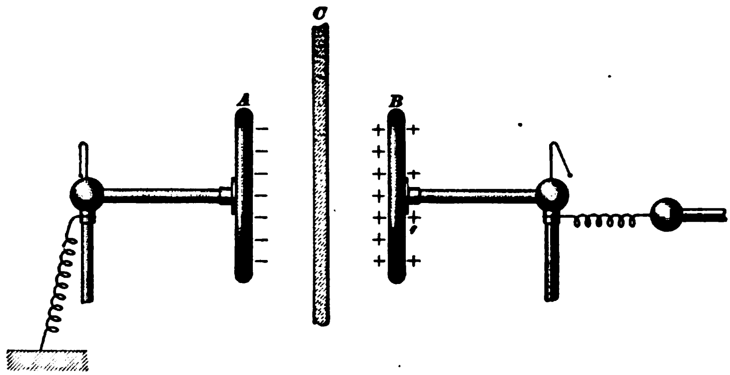


FIG. 16.

A greater quantity of electricity may therefore be put into the conductor before it is charged to as high a potential as it would be without the presence of the other conductor. Such an arrangement for holding a large quantity of electricity is called a *condenser of electricity*, or simply a *condenser.*

It is of importance to examine more closely the properties of such condensers. Let us therefore take two plates *A* and *B*, Fig. 16, interpose a glass plate *C* between them, and see what the effect will be when *B* is charged with positive electricity from some generator of static electricity and *A* is connected with the ground. The positive charge on B will, through the glass, induce a negative charge on A, and repel the positive electricity to the ground. The negative charge on A will collect on the face nearest B and react on the positive charge of the latter, attracting it nearer the glass, when more electricity will be supplied from the generating source. This inducing and reinducing across the glass will continue as long as the potential of the source is able to add new charges to B. In fact, the effect will be the same as though a current was constantly going from B to A through a constantly increasing resistance, and then to the ground.

If the two plates are brought nearer to the glass, the attraction between the charges will increase and the inductive action will be greater; a larger quantity can therefore be accumulated on the plates. After the disks have been strongly charged, the wires may be removed and the disks brought farther away from each other. The attraction between the charges will now be less; they will be less bound, and more of the charge will be free, and able to spread over the surface. That this is so can be seen by watching the pith-balls suspended from the conductors on each side. They will diverge, giving the impression that new charges have been added to A and B, while the fact is that the capacities of A and B have diminished, giving them the appearance of being more electrified than before, because there is a greater quantity of free charge. The ground-plate A has the effect of greatly increasing the capacity of an insulated conductor, the surface density on the side opposite the ground-plate being very great.

It will be noticed that in Fig. 16 the pith-ball pendulums do not diverge through the same angle; this is a result of the method of charging the condenser. It is evident that, when B is connected to the generating source, the right side of B and its rod will have the same potential as the machine, while the left side of A and its rod will have zero potential. When A and B are disconnected from the ground and generator, respectively, B still retains the surplus of electricity residing on its right side, while the left side of A is still at zero potential; hence, the pendulums will remain as before.

35. Condensing Force.—Let us denote the total quantity of electricity on B by 1; it will be possible by induction to retain a charge on A that is somewhat smaller, which charge we will call m; $\frac{m}{1}$ will then be the ratio of the charge on A to that on B. It follows that the charge m on A should be able to bind a charge on B bearing a similar ratio to itself, which would be $m \times \frac{m}{1} = m^2$. This quantity m^2 represents, therefore, the amount of charge held or bound on B by the charge on A. By subtracting m^2 from 1 we have $1 - m^2$ as the free charge on B, a charge that can be removed by connection with the ground.

This quantity $1 - m^2$ is all the electricity that would collect on B if alone; the ratio $\frac{1}{1 - m^2}$, therefore represents the so-called condensing force acting on the plate B. The value of m is found by experiments. If it were .99, the quantity of electricity that would collect on B would be $\frac{1}{1 - .99^2} = 50$ times the quantity it would be able to keep if alone.

36. Condenser of Unit Capacity.—The capacity of a condenser is defined by the number of coulombs necessary to be given to one coating when the potential difference between the two coatings is 1 volt.

A condenser is of *unit capacity*, or of *1 farad*, when a potential difference of 1 volt between its two sets of plates charges each one of them with 1 coulomb.

37. Conditions Governing Capacity.—That the size of the coatings influences the capacity of a condenser, and is directly proportional to the same, will hardly need a proof, because a large one may simply be supposed to be made up of several smaller ones. The aggregate area of one set of coatings of the smaller condensers would be equal to the area of one of the coatings of the larger.

We have already seen that the nearer the two conductors are placed, the more intense is the inductive action between them. It can be proved experimentally that the capacity of a condenser with plain parallel plates is inversely proportional to the distance between the coatings. We have also found that the dielectric medium plays an active part in induction, and that it is able to diminish or increase it, depending on the substance of which it consists. From this we conclude that the capacity of a condenser depends on (1) the size and form of the condensing plates; (2) the thinness of the dielectric medium between them; (3) the inductive capacity of the dielectric medium.

If the charge of a condenser in coulombs be called K, its capacity in farads F, and V its potential difference, then

$$K = F \times V. \qquad (a)$$

$$F = \frac{K}{V}. \qquad (b)$$

$$V = \frac{K}{F}. \qquad (c)$$

From formula (a) we see that K may be increased by increasing either F or V, or both. When used with static electrical machines, to be described later, the potential is usually made large, while for galvanic batteries and other sources of current having low potential the capacity is increased.

38. The Leyden Jar.—When it is desirable to have a high potential difference between two charges, the **Leyden Jar** is

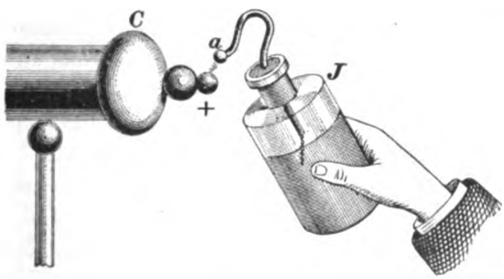


FIG. 17.

found to be a convenient form of condenser. It consists of a glass jar J, Fig. 17, coated up to a certain height on the inside and outside with tin-foil. A brass knob a is fixed on the end of a stout brass wire, which passes downwards through a lid or stopper of dry, well-varnished wood, and is connected by a loose piece of brass chain with the inner coating of the jar. To charge the jar, the knob is held to the prime conductor *C* of an electrical machine, the jar being held either in the hand by the outer tin-foil, or connected to the earth by a wire or chain. When a *positive* charge is thus imparted to the inner coating, it acts inductively on the outer coating, attracting a *negative* charge to the side of the outer coating nearest the glass, and repelling a *positive* charge to the outside of the outer coating. This outer charge passes through the hand, or any conductor connected with the jar, to the earth.

This form of Leyden jar has several weak points, the main one being the difficulty of keeping the outer and inner coatings well insulated from each other. It is known that moisture collects very readily on the surface of glass, and that this, and the dust that is always liable to collect, make it possible for the electric charge to leak from the brass wire across the stopper and the outside of the jar to the outside coating.

An improvement on this form of Leyden jar is one without any wooden lid or stopper, where the stout brass rod rests directly on the bottom of the jar, thus utilizing the whole length of the inside and outside glass surface, as well as the air-space between them, as insulators.

39. A form superior to either of these is one designed by Sir William Thomson, consisting of a glass cylinder with an outer coating of tin-foil, but half filled with strong sulfuric acid, instead of having an inner coating of foil. The brass rod is here supplanted by a leaden rod expanded at its base to form a foot so as to stand firmly on the bottom of the jar. The top of the jar is closed with a wooden cover having an aperture in it to avoid contact with the rod. The sulfuric acid absorbs all the moisture that may be present inside the jar, keeping the glass in a highly insulating state, and, as the rod does not touch the cover, no current can pass except through the liquid.

40. Location of Charge.—Benjamin Franklin discovered that the seat of the charge in a Leyden jar is not on the tin-foil, but on the glass. He proved this by so making the coatings of a jar that they could be separated from the jar after the latter had been charged. He then found that the coatings contained very little electricity. After having restored them to a neutral condition, the jar was put together again. It was now found to have a charge almost as large as before, proving that the coatings merely serve the purpose of distributing the charge over the surface of the dielectric.

41. Residual Charge.—It was also found that, after a Leyden jar had been "discharged," there remains a certain residue of charge on the glass, which after a while will emanate and collect on the surface, and will be able to give a second spark. This can be repeated a number of times, each succeeding spark becoming feebler and feebler. It is known that the dielectric between two charged coatings is subject to a certain *strain* or compression, so much so that a Leyden jar can be shown to have increased in volume, and when charged, if it is of thin glass, it may break under the strain.

42. Battery of Jars.—If the knobs and outer coatings of several Leyden jars are joined together, they will constitute a **battery of Leyden jars.** The potential difference between the two coatings will be the same, but its capacity will increase in proportion to the number of jars. A battery of this kind must be handled with great care, as a shock from it may be very severe.

43. Isolated Charges.—In the preceding pages we have spoken several times about isolated charges, either positive or negative, on insulated bodies. This has been done for the sake of convenience, so as not to unnecessarily complicate the subject in hand; but if the student has taken the matter of induction well under consideration, there will by this time have been aroused doubts in his mind as to whether an isolated charge of any kind really could exist.

It has been shown that the induction between two bodies will decrease with the distance between them; from this it would be supposed that, when these experiments were performed in the limited space of a room, the surrounding objects would be subject to induction. The fact is we cannot charge one body alone—cannot place a single charge of electricity anywhere without having an equal quantity of opposite sign somewhere else. Neither is it possible to have two bodies charged with the same kind of electricity without having a third body charged with a corresponding quantity of the opposite kind.

Let Fig. 18 represent a room A with two conducting bodies B and C placed therein, both charged with positive electricity. We know from our previous investigations in induction that a charge of a negative kind will be induced on the walls of the room, and that the charges on the conductors will be distributed unevenly on their surfaces, in a manner illustrated in the figure. We have said that two conductors charged with positive electricity will repel each other; it has also been quoted as a fact that two conductors oppositely charged attract each other.

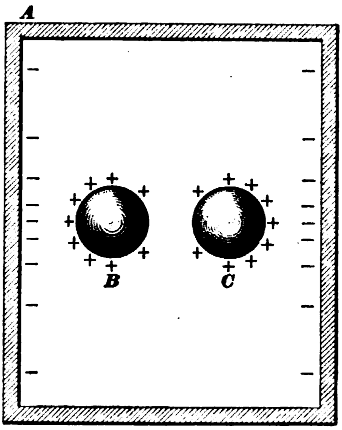


FIG. 18.

In the present instance, B and C move away from each other and tend to approach the walls; but what is the cause of this? Is it attraction or repulsion? As it has never been possible to study the behavior of two similarly-charged bodies at an infinite distance from any other bodies, it is really not known whether it is possible for two charged bodies to repel each other. It is therefore probable that, when an apparent repulsion takes place between the bodies B and C, their motion is in reality caused by an attraction between them and the adjacent walls. It will therefore be seen that every charged body forms a condenser with some other adjacent body, be it the floor, ceiling, or walls of a room, or pieces of furniture, or the experimenter himself; they all have some influence, one perhaps more than others, depending on its position or the presence of a charge on its surface. To have a charged conductor so placed that its charge will be evenly distributed, unaffected by its surroundings, will therefore be a condition very difficult to fulfil.

STATIC MACHINES.

44. As the electric charges that are obtainable from an electrophorus are rather limited in quantity and of relatively low potential, machines were early devised for the production of large electrostatic charges. There are two important types of electrostatic, or, as they are usually termed, **static, machines.** The older of these machines, the *frictional* machine, has now been almost entirely superseded by the *induction* machine.

STATIC FRICTIONAL MACHINES.

45. These machines are now obsolete, but as a description of them makes it easier to grasp the principle of the influence-machine, they will here be treated first. There are two classes of these: the *cylinder* machine and the *plate* machine.

THE CYLINDER-MACHINE.

46. This machine consists of three principal parts: (1) a cylinder of glass revolving upon a horizontal axis; (2) a rubber

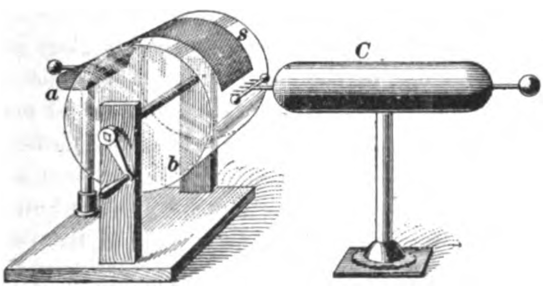


FIG. 19.

or cushion of horsehair, to which is attached a long silk flap; and (3) an insulated metallic cylinder called a **prime conductor.**

In Fig. 19, the cushion of horsehair *a*, covered with a coating of amalgam of zinc, presses against the glass cylinder *b* from behind, allowing the silk flap *s* to rest upon the upper half of the glass. The prime conductor *C* is provided at one end with a row of fine metallic spikes, and is placed in front of the machine with the row of spikes projecting towards the glass cylinder. When the glass cylinder is revolved, a *positive* charge is produced upon the glass and a negative charge upon the rubber. The positive charge is carried around upon the glass cylinder, and acts inductively on the prime conductor, attracting a negative charge to the near end, and repelling a positive charge to the far end, whence it can be collected. The row of spikes is therefore strongly charged with negative electricity. The effect of charged points upon surrounding air has already been noticed; in the present instance a strong current of negatively-charged air will be driven against the positively-charged cylinder, thus neutralizing the positive charge and leaving the glass in a neutral condition, ready to be excited again. Sometimes the action of the spikes is somewhat erroneously stated to be that of drawing the positive charge from the cylinder.

When the cushion is insulated from the ground by being mounted on a glass rod, as in the present instance, the negative charge can also be collected from the brass knob, visible at the rear of the cushion.

THE PLATE-MACHINE.

47. The **plate-machine** is similar in all respects to the cylinder-machine, with the exception that a glass or ebonite plate is used instead of the glass cylinder, and that there are usually two sets of rubbers or cushions instead of one. Each set of cushions is double—that is, made in two parts—with the plate revolving between them. One set of cushions is placed at the top of the machine and the other at the bottom, with silk flaps extending from each over a quadrant of the plate. The charge is collected on two prime conductors connected by a metal rod, each provided with a row of fine spikes at one end. They are placed in such a position that the two rows of fine spikes project towards the glass plate at opposite sides of its horizontal diameter. The electrostatic action of the machine is in all respects the same as that of the cylinder-machine.

Both the cylinder- and plate-machines are nothing else than machines imitating the frictional action of rubbing a glass rod with a piece of silk, the action being made continuous and on a larger scale. As the electrical energy stored up by rubbing the glass rod and separating it from the silk was simply the work done in separating them, and not in any way proportional to the energy lost in friction, so with the frictional machines all the useful work consists simply in separating the positively-electrified portions of the rotating glass cylinder or plate from the negatively-electrified silk cushions. Most of the work expended in turning the glass plate against the frictional resistance of the cushions is completely lost in heat. The machine is therefore very inefficient, and a method had to be devised by which this large amount of friction should be eliminated. This was found in improved types of static induction-machines, which have at present completely driven the friction-machines out of the field.

STATIC INDUCTION-MACHINES.

48. Fundamental Principles.—When the action of the electrophorus was considered, it was seen that its action was founded on induction entirely. As an apparatus for delivering charges by induction it is a very good example, but one objection to it is its slowness of action. We can imagine this overcome by an arrangement in which the disk would move backward and forward between the cake and an outside contact, constantly charging the latter with positive electricity ; but even then there is a serious fault inherent in the method, namely, the impossibility of raising the potential beyond that of the cake. Here it is that the great advantage of the induction-machine comes in, where it is practically possible to begin with a small initial charge, and, by adding to it little by little, increase it until at last a very high potential is reached.

The apparatus illustrated in Figs. 20 and 21 will give a good idea of the principle on which the influence-machine rests. It is mainly a repetition of the experiment with the electric cage illustrated in Fig. 15. *D* and *E* are two metallic cylinders insulated from the ground ; there is a small potential difference between them, D having a small positive and E a small negative charge. A and B are two neutral conductors, suspended by silk threads; in Fig. 20 they are shown to be in communication with each other by means of the thin wire W fastened to the insulating stand C. The following will now take place: D will attract a negative charge on the ball A and repel a positive, while E will attract a positive charge on the ball B and repel a negative. The positive charge repelled on A will unite with the negative charge repelled on B through the wire W, and they

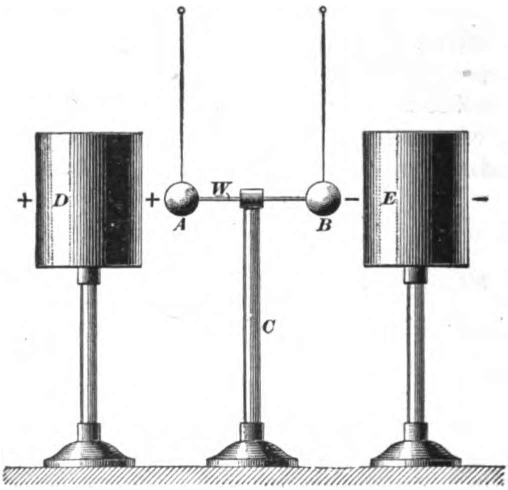


FIG. 20.

will neutralize each other, leaving a bound positive charge on B and a bound negative charge on A. If now the communication between the balls is broken by removal from the wire W, and A is inserted in cylinder E, and B in cylinder D, they will both induce charges of an opposite kind inside their respective cylinders, repelling a charge of the same kind to the outside, as represented in Fig. 21. When at last the balls make contact with the cylinders, the charges on the inside will unite with those on the balls and neutralize one another, resulting in an addition to the positive charge on D and the negative on E. When A and B are removed from their respective cylinders, they are entirely discharged, and can again be placed in the position indicated in Fig. 20; but as they are now subjected to a stronger induction, the bound and free charges will be greater, and they will be able to deliver greater charges to the cylinders. It can easily be seen that, by repeating these manipulations, the potential difference between *D* and *E* will con-

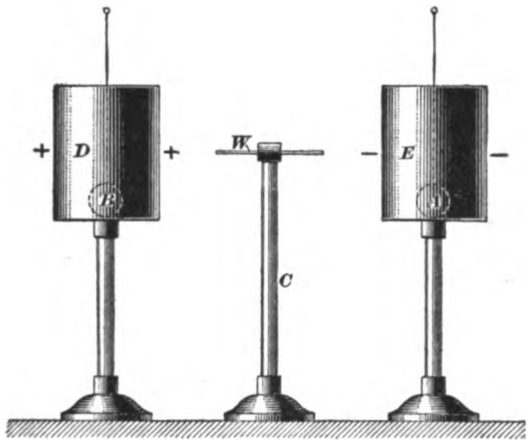


FIG. 21.

stantly increase, and will after a while be very high; it may indeed be said to increase at the rate of the *compound-interest law.*

THOMSON'S REPLENISHER.

49. Construction and Action.—An apparatus built on these principles, but continuous in its action, and called a **replenisher,** was devised by Sir William Thomson (in 1867), and is illustrated in Figs. 22 and 23 in diagrammatic views. In order to better compare them, the parts corresponding with those of Figs. 20 and 21 have been marked with the same letters. *D* and *E* are stationary brass conductors, *A* and *B* brass carriers fastened to the ends of an arm *F*, made of ebonite and revolving with the spindle *G* in the direction indicated by the arrow. In place of the wire *W* in Fig. 20, we have here a wire *W* with two springs *W'*, and, instead of touching the cylinders with the balls, as represented in Fig. 21, there are two contact-springs *S*, *S* projecting through an aperture in the inductors, and connected electrically with them. It is supposed that *D* has a small positive charge, and *E* a small negative one. Fig. 22 represents the position at the moment when *A* and *B* are under the inductive influence of the conductors *D* and *E*; at the same time they are connected with each other by means of the springs *W'* and wire *W*. Negative electricity is bound on the exterior side of *A*, while a positive charge is made free; on *B* a positive charge is bound, while a negative charge is free. The free charges will unite through the wire *W* and neutralize each other, and, when *F* continues its rotation, there will be a free negative charge on *A* and a free positive charge on *B*. Fig. 23

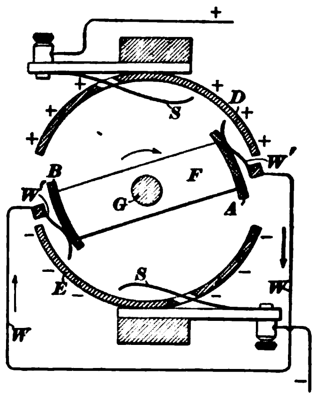


FIG. 22.

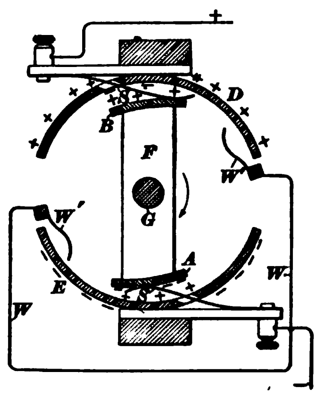


FIG. 23.

represents the position in which the carriers make contact with the springs *S*. The negative charge on *A* attracts positive electricity to the inside of *E*, and repels a negative charge to the outside; the spring *S* establishes communication between the negative charge on *A* and the positive charge on *E*, and a neutralization takes place, leaving on *E* an increased negative charge. A similar action takes place on *D*, leaving it more strongly charged positively. The carriers *A* and *B* are now discharged, and, when they again reach the springs *W'*, they will be subject to a stronger induction than before, and will thus continue adding to the charges on the inductors. If the action of this "replenisher" is thoroughly understood, it should not be difficult to understand the action of the modern induction-machine, which ordinarily, without due study, is not quite easy to grasp.

The most important types of this class are the *Toepler*, *Holtz*, and *Wimshurst* machines, so named after their inventors. In this country the Toepler and Holtz machines are mostly used, but as the latter is not self-charging it is provided with a Wimshurst machine for the purpose of giving it its initial charge.

THE TOEPLER MACHINE.

50. Introductory.—The static induction-machine was independently invented by Toepler and Holtz in 1865. The principles of both are very similar, though they differ somewhat in construction. There are variations or combinations of both, but these may be easily understood, when the fundamental principles have been studied.

The Toepler machine may be considered as a Thomson replenisher, the difference being that the carriers are placed on revolving glass plates instead of forming parts of a cylindrical surface, and that the number of carriers is increased. It may simplify matters by first explaining the action of the Toepler machine in the form of a replenisher, and then give an example of its practical form.

51. Principles of the Toepler Machine.—In Fig. 24 we find a diagrammatic view of such a replenisher, varied so as to correspond in action to that of a Toepler machine. D and E are *field-plates* made of tin-foil attached to the outside of the glass cylinder A, which is stationary. B is another cylinder, which is revolving in the direction of the arrow x, and is provided with *carriers* a, b, c, etc., also made of tin-foil. To obviate the necessity of the brushes w_1 and w_2 touching the carriers, small metallic buttons n are attached to the latter, which serve the purpose of transmitting the charges from the carriers to the brushes. We will now suppose that the field-plate D possesses a small positive charge, and that the carrier a is under its inductive influence. A negative charge will then be attracted in the latter towards the side facing D, and will be bound, while a positive charge will be repelled and flow into the *neutralizing brush* w_1, which connects with the other brush w_2 possessing a negative charge. The charges will neutralize each other, leaving a in possession of a bound negative charge. As soon as the carrier a passes away from D and is no longer under its inductive influence, the bound negative charge will be free, and will, when the carrier passes under the brush s, be collected by the latter and sent into the field-plate E, which is then negatively electrified. This field-plate will now, when the carrier a occupies the position of carrier d, induce a positive charge on the side facing it, and repel a negative charge towards the side next to the comb C_1. The same action will then take place that was described in Art. **46**; that is, positively-charged air will be driven from the comb C_1, neutralizing part of the free negative charge on the carrier. The conductor P_1 is thus given a negative charge. When the carrier now proceeds

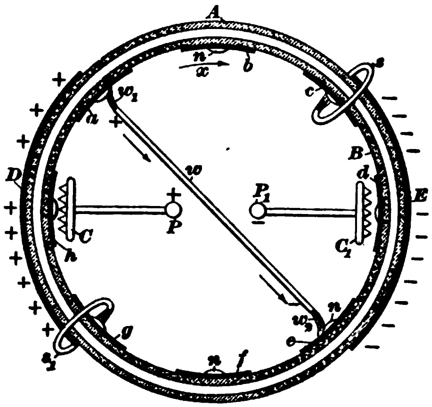


FIG. 24.

to the position e, the neutralizing brush w_2 will remove whatever negative charge is left, and combine it with the positive charge taken up by brush w_1, so that, when the carrier proceeds to occupy the position f, it is in possession of a free positive charge. This charge will now be of a higher potential than that on the field-plate D, and, when communication is established between the two charges by means of the brush s_1, an equalization will take place, and both will be of the same potential, thus increasing the potential of D.

52. The Carriers.—The carrier, when moving into position h, will induce a negative charge on the comb C, causing negatively-charged air to be driven against the carrier, and thus making the other end P the positive terminal of the machine. Whatever positive charge is left on the carrier will, when it reaches the position a, be neutralized by the negative charge on the carrier c, so that carrier a is again in possession of a negative charge, but stronger now than the charge that resided on the carrier when we began our cycle.

We see, then, that the carriers, when leaving the position a, have free negative charges, which they deliver to the field-plate E, while the carriers after leaving this field-plate are ready to deliver positive charges to the field-plate D. The potential of these two plates will be increased until the leakage between them keeps up with the supply, when a further increase is prevented.

At the same time that the potential of the field-plates has been raised, that of the free charges on the carriers has also been increased, and thus induced charges of progressively higher potential will be set free at the terminals of the conductors P and P_1.

53. The Toepler Machine.—There will now be little difficulty in understanding the action of the **Toepler machine,** as illustrated by Fig. 25. For the sake of making comparison easier, the same letters have been used as in Fig. 24, on those parts which have the same functions to perform. Thus, A is a stationary glass plate, shown separately in Fig. 25 (c), on the back of which the field-plates D and E are cemented. Each field-plate consists of a piece of tin-foil, the surface of which is protected by a layer of varnished paper. The movable plate with the carriers is B, as before, and the carriers are a, b, c, d, e, f. As the latter are of tin-foil, and therefore liable to injury by the rubbing of the tinsel brushes S and S_1, they are provided with small brass buttons a_1, b_1, etc., shown in Fig. 25 (b), which alone make contact with the brushes, and thus shield the carriers.

Fig. 25 (a) shows the plates in position, the revolving plate B being in front. If we again suppose the field-plate D to have a small positive charge, the carrier a will have a *bound* negative and a *free* positive charge. The latter will be removed by the neutralizing brush w_1, and the carrier will therefore reach the position b with a *free* negative charge, which will be imparted to the field-plate E by the brush S, as already shown. It is

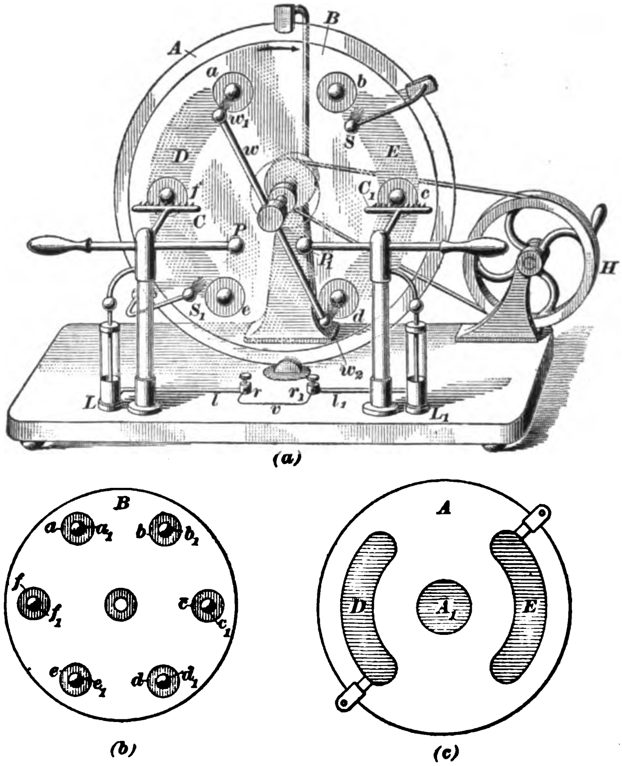


FIG. 25.

unnecessary to describe the operation any further, as it is exactly the same as that of Fig. 24.

54. It is seen that the plate A and the collectors are supported by glass columns, to insure perfect insulation. The discharge-rods P and P_1 can slide in their supports, thereby making it possible to change the length of the air-gap between the two rods. These discharge-rods are also electrically connected with the Leyden jars L, L_1, which will accumulate the electric charges of the rods, reducing the number of sparks, but increasing their strength. The outer coatings of the jars are electrically connected by means of strips l, l_1, binding-screws r, r_1, and wire v. The charges passing between terminals r, r_1 can also be sent through various appliances, or through the human body.

The plate B is set in rotation by means of the pulley H, which engages a smaller pulley on the shaft of B. When starting the machine, the brushes should be set so as to make good contact with the revolving carriers, and the discharge-rods should be drawn widely apart. A few turns will then suffice to charge the machine, and, if the discharge-rods P, P_1 are now brought closer together, sparks will pass between them.

It should here be remembered that positive charges are not sent into the comb C from the plate and transferred from there to the rod P, but that negative charges are constantly withdrawn from the comb and neutralized by the carriers, leaving a positive charge on the end of the discharge-rod at P.

When P and P_1 are near enough to permit sparks to pass between them, the positive charge on P will be neutralized, but a negative charge will immediately be withdrawn from the comb C, leaving a positive charge again at P, as before. The reverse takes place at the positive comb C_1; here positive charges are constantly sent towards the plate, thus leaving negative charges on the discharge-rod P_1.

55. Though the carriers perform most of the work of carrying the + and — charges from brush to brush and to the combs, it must not be supposed that the plate B is neutral. On the contrary, this plate could work even without the carriers, but it would be difficult to put the machine in operation. After the machine is once in action, this glass plate is also in possession of a strong positive and negative charge, placed diametrically opposite each other, which, as their potentials increase, tend to leak across the plate and unite with each other. This action of the plate, therefore, limits the possible potential that the carriers otherwise might have attained.

In most types of Holtz machines the carriers have been omitted, and the neutralizing brushes w_1, w_2 replaced by neutralizing combs. To facilitate the starting of the machine, the field-plates *D*, *E* are connected with a small Wimshurst machine, which gives them a high initial charge, after which the machine at once is in full action, and able to maintain the charges. This machine is described in Art. **61.**

THE WIMSHURST MACHINE.

56. Principles of Construction.—Another type of induction-machine is the **Wimshurst machine,** which has been very extensively used in Europe. Though in some respects it is superior to the Holtz machine, it has not gained ground in this country, so far as its use in therapeutics is concerned; it seems that the strength of current it is able to furnish is smaller than that of a well-made Holtz machine, and that it is, as regards mechanical construction, less enduring than the other. It has this advantage over the Holtz machine, that it is self-starting, and is therefore used very extensively in combination with the latter machine, it being always ready to furnish the necessary initial charge.

57. Fig. 26 will explain the main principle of this machine. *A* and *B* are glass cylinders provided with carriers numbered

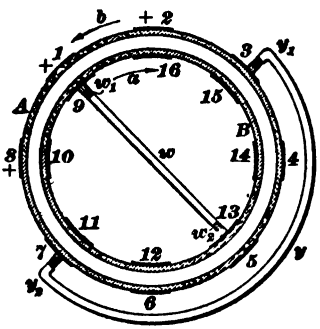


FIG. 26.

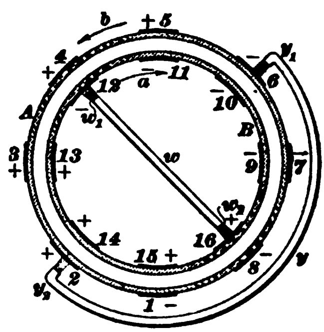


FIG. 27.

1, 2 . . . . 8, and *9, 10 . . . . 16*; w_1, w_2 are the neutralizing brushes for the interior, and y_1, y_2 the neutralizing brushes for the exterior cylinder. We will first suppose that the exterior cylinder is stationary, and the interior revolving in the direction of the arrow *a*. Let it further be supposed that the carriers *8*, *1*, and *2* have an initial positive charge. The carrier *9* will then be subjected to an inductive influence due to these three carriers, and it will therefore assume a bound negative charge, and the free positive charge will be neutralized by the brush w_1.

When the carrier *9* changes its position to that of carrier *15*, it will be removed from the inductive influence of the positively-charged carriers, and will have a free negative charge of a slightly higher potential than that held by *8*, *1*, or *2*. When, then, carrier *9* occupies the position of carrier *15*, it is inducing a positive, bound charge on carrier *3*, and a free, negative charge is neutralized through the brush y_1.

If we now set cylinder *A* in rotation in the direction of the arrow *b*, carrier *3* will subsequently reach the position of carrier *1*, where its positive charge is free and of a higher potential than that possessed by carrier *1*. The fact that each carrier on these cylinders is exposed to the inductive influence not only of the carrier placed opposite, but also to that of the adjoining carriers, constitutes the main feature of the Wimshurst machine. This explanation of its action appears as acceptable as any, and is justified by the fact that the Wimshurst machine will work to better advantage with, say, sixteen sectors per plate than with a smaller number. Ordinarily, these carriers are much closer together than shown in the diagram, and their combined action is therefore much stronger. If each carrier were able to influence only the carrier confronting it, no increase in potential could be gained, and the charges would soon decrease; but, as it is, the charge induced on each carrier is appreciably stronger, if it is under the joint inductive influence of more than one carrier instead of one only.

58. Fig. 27 shows the condition of the machine after each of the cylinders has made three-eighths of a revolution. We find then that one-half of each cylinder is positively, the other half negatively, charged; in either case the neutralizing rod constitutes the dividing line.

59. Fig. 28 shows a similar machine, in which all the brushes have been replaced by combs, and the carriers removed, leaving bare glass cylinders. For collecting the charges, the combs C and C_1 have been added. The diagram plainly shows the condition of the glass cylinders, and how the free charges are neutralized by the combs C, C_1, thus leaving the conductors P and P_1, respectively, positively and negatively charged.

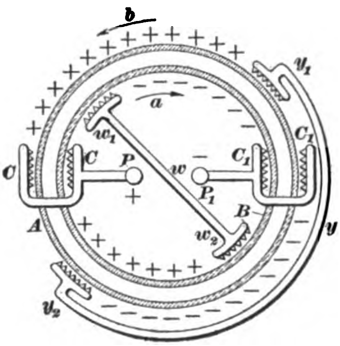


FIG. 28.

60. Fig. 29 gives a perspective view of a Wimshurst machine. The glass cylinders used in the previous description are here replaced by two glass plates A and B, on the outside of which are cemented a number of sector-shaped plates, serving as carriers and inductors. The function of these sectors is changed twice during each revolution of the plates, from a carrier to an inductor, the carriers on one plate serving as the inductors for the carriers on the other plate. These glass plates are coated with shellac, and are attached to the ends of two hollow bosses of wood or ebonite provided with pulleys. Each plate revolves independently on a fixed steel spindle S, motion being imparted to the pulleys by means of cords passing over corresponding pulleys in the lower part of the machine. The plates are $\frac{1}{8}$ inch apart, and are revolved in opposite directions by crossing one of the cords. The curved conductors w, y, with fine-wire brushes at their ends, are the neutralizing rods, and are placed at an angle of about 90° with each other. Two metallic conductors F and G have

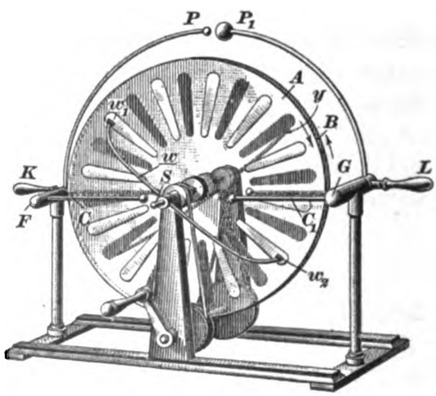


FIG. 29.

each two collecting-combs C and C_1, one for each plate. These conductors are, as usual, insulated from the ground by means of glass columns, and carry two discharge-rods P, P_1, terminating in balls; the distance between these can be changed by moving the handles K, L either up or down.

A Wimshurst machine will be able to maintain charges of a higher potential if the carriers are removed, but it will not start quite as readily. The use of the carriers has the disadvantage that it changes a large part of the revolving plate into a conductor, and thus facilitates the leakage between charges of opposite potentials.

THE HOLTZ MACHINE.

61. Theory of Action.—The Holtz machine is entirely without carriers, and the replenishing brushes S in Fig. 25 have been replaced by some other device. By eliminating the carriers, the machine is able to give a somewhat larger volume of current, but at the same time it loses its self-starting properties. Machines of this class have, therefore, to be supplied with a smaller auxiliary machine that will supply an initial charge. These charging machines are usually of the Wimshurst type, with or without sectors.

The Holtz machine is made of plates similar to the Toepler machine, Fig. 25, but its action may be better understood by the diagrammatic view given in Fig. 30, where the plates are shown in the form of cylinders. The simplest principle by which its action may be explained is that of subtraction of charges, as mentioned in Arts. **46** and **51.** The main parts of the machine are the two inductors D and E fastened to the outside of the two semicylinders A_1 and A_2. At one end these inductors are provided with paper-tongues d and e. B is the rotating cylinder made of well-varnished glass and having in its interior the two prime conductors P_1 and P_2 with the collecting-combs C_1 and C_2. The purpose is now to supply the two inductors D and E with charges of constantly increasing potential, and then let these charges act inductively on the revolving cylinder B and the combs C_1 and C_2.

We will suppose that the inductor D is given a positive charge that will induce a bound negative charge on that part of B that is facing D, and a free positive charge on the inside of B near the comb C_2. This positive charge in connection with that on D will act inductively on C_2 withdrawing negative charges that will partly neutralize the positive charges on B, and by thus constantly withdrawing negative charges through C_2, the conductor P_2 will be left positive. That part of the positive charge on B that was not neutralized by the comb will be withdrawn

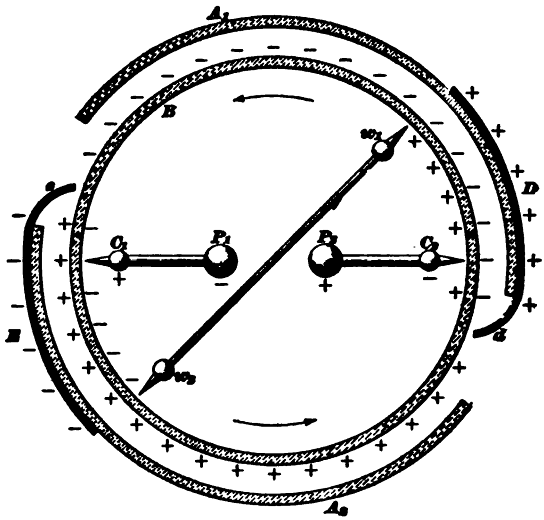


FIG. 30.

by the neutralizing rod w_1 w_2 by giving it an opportunity to combine with a negative charge at w_2.

It is seen that when the cylinder B emerges from under the influence of the inductor D it will be in possession of a free negative charge that will be carried around towards the tongue e, where positive charges will be withdrawn that neutralize the charges on B and at the same time make the inductor E negative. The latter will now in return act inductively on B and comb C_1 producing a positive, bound charge on B and withdrawing positive charges from the comb C_1 that will partly neutralize the free negative charges on the interior side of B.

The conductor P_1 will be left negative and the cylinder B will advance from under the neutralizing comb w_2 with free positive charges, that will be neutralized by withdrawing negative charges from D, leaving the same thereby still more positive. This increase in the difference of potential between D and E will continue until the leakage of the charges is so great that it keeps step with the supply of fresh charges.

When it is desired that any induction-machine shall deliver a current of greater volume, then the number of plates is increased. The plates may then be said to be connected *in parallel* as each plate delivers charges of the same potential to a common conductor where the charges are combined into one of increased volume, but of the same potential as that of each individual plate. The number of revolving plates may vary from 1 to 16, or more, with a diameter of from 24 to 36 inches. Holtz machines of this size are fully illustrated elsewhere.

MODES OF DISCHARGE.

62. It has been stated previously that there were not different classes of electricity—that, no matter by what means a difference of potential was created, the same kind of electricity would flow. Its elementary nature would always be the same, but it might be made to show different characteristics in the manner of flowing, by variations in the apparatus. For instance, it might be a *continuous*, or *pulsating*, or an *alternating* current. These three variations refer mainly to the character of its flow through a conductor, but for a *high* electromotive force there are also other means open for a discharge. It may take place in any of the following three forms: (1) by *conduction;* (2) by *convection;* (3) by *disruption.*

CONDUCTIVE DISCHARGE.

63. The *conductive* form of discharge, when it takes place under moderate pressures, has already been fully considered in *Direct Currents.* When the higher pressures, such as those produced by means of a static machine, are given an opportunity of starting a current, other and more complicated phenomena will manifest themselves. But as such charges of high potential mostly are given the opportunity to unite by means of a spark, they properly come under the head of disruptive discharges, and will therefore be considered under that heading.

CONVECTIVE DISCHARGE.

64. We have already seen how a *convective* discharge took place in the induction-machine when the collecting-combs discharged their induced charge by means of electrified air repelled towards the revolving plates. A pointed metallic rod connected with the prime conductor of a machine will discharge itself in this manner if the electromotive force exceeds 20,000 volts. This motion of the air is called an electric *breeze*, and is utilized as such in electrotherapeutics.

DISRUPTIVE DISCHARGE.

65. The third form of discharge, the *disruptive*, has been observed when the electrophorus was considered. It was noticed that, after the disk had been removed from the cake and then approached by one of the hands, it would discharge itself by means of a spark. The same thing will take place if the discharge-rods of a static machine are brought near enough together.

It has been found experimentally that it takes a potential difference of about 8,000 volts to send a spark between two metal balls separated by an air-gap of $\frac{1}{10}$ inch, so that it would take about 80,000 volts to send a spark through a gap of 1 inch. If one of the conductors is pointed and the other provided with a plate, the necessary voltage for a 1-inch gap will be decreased to about 23,400 volts. This applies to a distance of up to 3 inches; beyond this the voltage per inch decreases.

The distance between the discharge balls of a static induction-machine determines the maximum potential difference that can be developed between them; if, therefore, the balls were separated a distance of $\frac{1}{2}$ inch and the machine turned just fast enough to send a spark across, we would know that the potential would be about 40,000 volts.

These relations between voltage and sparking distance do not hold true when we have to do with an alternating current, such as derived from an induction-coil. It is not the *virtual* voltage that is here the deciding factor, but the *maximum* voltage. To send a spark across an air-gap of 1 inch with an ordinary induction-coil will therefore require less voltage, or from 40,000 to 50,000 volts.

66. It is usually supposed that when a disruptive discharge occurs there is simply a transfer of a given electric charge from one conductor to another, and that the violence of the discharge causes the visible spark. This is natural, because the rapidity with which the discharge takes place makes it impossible for the human eye to detect the real nature of the phenomenon. But by means of more sensitive apparatus, such as revolving mirrors, the observer will be able to see that instead of one discharge we have in reality to deal with a series of discharges. This should not be surprising, as it has been shown that an electric current behaves as if in possession of inertia. When, therefore, a current of electricity is sent through a conductor under such high pressure as a static machine is able to produce, it would seem natural that the current, after once being started, would tend to continue its motion, creating a reverse pressure.

A swinging pendulum works under somewhat similar conditions. On pushing it to one side and releasing it, it will not stop in its original position, but will pass beyond this to the other side. It will again return and will continue this oscillating motion until the energy imparted to it has been wasted in overcoming frictional resistance. With no resistance to overcome, the oscillations would continue forever.

67. It must not be understood from these remarks that discharges taking place under high pressure are *always* oscillatory. This is not the case; certain conditions have to be fulfilled before a discharge of this nature will occur. There has to be a certain relation between the resistance of the circuit, its self-induction, and its capacity; otherwise, the discharge will take place as ordinarily, that is, by a gradual equalization of the positive and the negative potential.

To return to the case of the swinging pendulum; we can, for instance, well understand that, if a large fan be fastened to the pendulum, the air resistance may be so great that the pendulum would slowly swing to its middle position and stop there. In the same manner, if the conductors of a static induction-machine are connected by a slightly damp linen thread, the discharge will pass through it more gently, and oscillations will not be set up.

This slow conductive discharge may be compared with a light body falling slowly towards the earth, and settling down gently. The disruptive discharge, on the other hand, is more like the action of a steel ball falling from a certain height on to a metal plate. It will rebound again and again, and little by little come to rest.

68. Interaction Between Resistance, Self-Induction, and Capacity.—To better understand the relation between resistance, self-induction, and capacity, we may again use a hydraulic analogy that would correspond to the combination of two Leyden jars connected to the prime conductors of a static machine or to an induction-coil. Let *A* and *B*, Fig. 31, be two cylinders filled with water and provided with two pistons *c* and *d* that may move freely up and down. Ordinarily, the two pistons stand at the same level, but in this instance the piston *d* has been pushed down, thereby raising *c* to a higher level, after which the valve *g* is closed. The pistons will remain in this position because communication between the two cylinders has been broken.

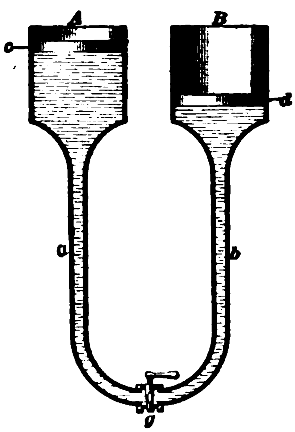


FIG. 31.

If, now, the valve *g* is opened suddenly, water will flow from cylinder *A*, so as to reestablish the former level, and the water-columns in pipes *a* and *b* will be set in motion. After the pistons have reached their middle position again, the water, by reason of its inertia, will tend to keep up its motion, and therefore to move the piston *d* to a higher position. As soon as the energy of the moving water has been consumed in raising the water in cylinder *B*, thereby changing the kinetic energy that the water possessed into potential energy, the water comes to rest. The water in *B* will now seek to use the potential energy it has received, in setting the water-column in motion again in the opposite direction. When the pistons are passing through their middle positions the potential energy has all been changed into kinetic energy, and the water is now flowing at a maximum rate. Again, the inertia of both water-columns tends to maintain the motion, and now the piston *c* will be raised to the higher position. If the water, the pipes, and the moving parts were devoid of all friction, the to-and-fro motion would continue indefinitely, without any diminution in the amplitude of the oscillations. But it is easily seen that their combined friction will soon consume the energy originally imparted to the water, and the oscillations will therefore gradually decrease in amplitude, and at last cease altogether.

69. Let us now see how the character of these oscillations is influenced by the dimensions and nature of the circuit. It is clear that the wider the cylinders *A* and *B*, the more water can flow in or out of them before a greater change in level occurs. This rise of the water-level will produce a counter pressure that will tend to stop the ingress of the water. The more slowly this increase in pressure goes on, the more water can flow in before the stored-up kinetic engergy is transformed into potential energy. They are then said to be of great *capacity*.

If the inside of the pipe is rough, thus offering much *resistance* to the flow of the water, more energy will be consumed in friction and less will be left for raising the level of the water in either cylinder. It is seen that if this resistance is made large enough, the return of the water to its original level, might be so slow and consume so much energy that it would not be able to reach it again.

It will also be seen that the length and diameter of the pipes will have some influence, as these dimensions determine the volume of water contained in the pipes. A given amount of energy will require a longer time to set a large volume of water in motion than a small one; and a large volume, after once being set in motion, will continue this motion against an opposing force for a longer time than a smaller volume of water is able to do. In both instances, the *inertia* of the water tends to oppose both the beginning and cessation of motion.

70. The conclusions we arrive at are, then, as follows: That in order to have the water-column perform oscillations, the resistance of the pipes has to be below a certain value, otherwise there will only be a gradual discharge in one direction. To have long and powerful oscillations, the volume of water set in motion must be large and also the capacity of the cylinders. If, on the other hand, the capacity of the latter is small, it will require only a small quantity of water to enter either cylinder before the piston is raised to its highest point; the oscillations will therefore be of short duration, and their frequency will increase as the capacity of the cylinders decreases. It is seen from this that it is not possible to have a large volume of water perform oscillations of great amplitude and high frequency, because a high frequency requires a small capacity of the cylinders, while, on the other hand, a great amplitude demands a large capacity.

71. When a disruptive discharge takes place between the two conductors *a* and *b* connected with the Leyden jars *c* and *d*, Fig. 32, we find somewhat similar conditions. As soon as the difference of potential between the two conductors has increased to a point where the positive charge on *A* and jar *c* is able to bridge the intervening air-gap, oscillations will begin. At the moment when a sufficient amount of the charge on *A* has passed over to *B* and jar *d*, so as to neutralize the difference of potential, then the potential energy of the charge has been changed into kinetic energy, and the current is then flowing at a maximum rate, as was the case in the hydraulic circuit. The self-induction or electromagnetic inertia of the current carries it beyond the point where a balance in pressure was attained, and it continues to flow into the jar *d* until the latter is in possession of a positive charge of a potential high enough to counteract the kinetic energy that the current possessed. In the jar *c* the opposite will have occurred—it will be negatively charged. A reverse current will now be sent across the spark-gap and the conditions will again be reversed. These oscillations of the charge will continue until its original energy has been used up, partly in heating the air in the spark-gap and partly in setting up ether waves in space.

The volume of the Leyden jars, that is, their electrostatic capacity, has the same effect as the cylinders in Fig. 31. The greater their capacity, the greater amount of electricity may

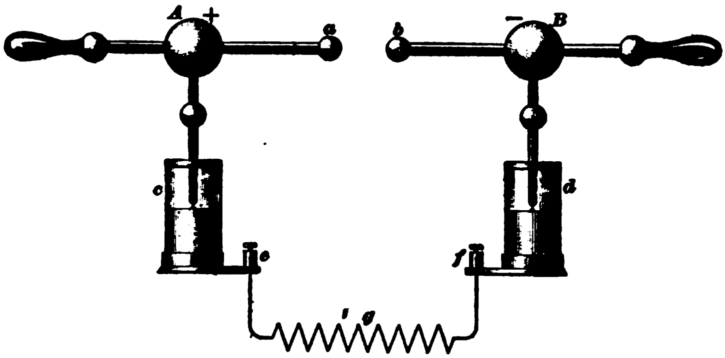


FIG. 32.

pass into the jars before their potential is raised to a certain value, and the more sluggish the jars will act in returning the charge. By decreasing the capacities of the jars it will require smaller charges to obtain the same potential and the oscillations will be carried on more quickly.

The resistance of the electric circuit plays also the same function as in the hydraulic one.

72. Examining into the conditions required for an oscillating discharge, we observe that the production of rapid, and at the same time powerful, oscillations will meet with some difficulty. To have rapid electric oscillations, the electrostatic capacity and self-induction must be small. On the other hand, long and powerful oscillations require a current of great strength and a circuit with a large electrostatic capacity. But a strong current has a large amount of self-induction. We see, therefore, that rapid oscillations cannot be combined with a strong current, but must go hand-in-hand with a feeble one.

The rapidity with which these oscillations take place is far beyond anything we are able to produce by mechanical means. Their frequency may be as high as 100,000,000 per second, depending on the capacity of the jars and the self-induction of the circuit. As the visible spark itself lasts only a small fraction of a second, so must necessarily the total number of these oscillating discharges, that collectively constitute a spark, be few in number.

It was shown when the induction-coil was considered that the E. M. F. produced in the secondary coil was, other factors remaining the same, directly proportional to the rapidity with which the current in the primary coil was interrupted. It will therefore be obvious that with the enormously rapid interruptions, which a disruptive discharge is able to provide, E. M. F.'s may be produced in a secondary circuit that exceed any such produced by ordinary means. Even a primary current of relatively small strength may by these means be able to induce a secondary current of a very high E. M. F.

THE STATIC MACHINE IN ELECTROTHERAPEUTICS.

73. The Various Modes of Applying Static Electricity.—Detailed information about the technique of static electricity is given later in this Course, but as it will be of benefit to the student to understand the electric phenomena on which the various modalities are based, they will here be considered successively, beginning with the simpler and progressing to the more complex.

The treatments in which the static machine is employed are generally divided under the following headings:

1. General electrification or charge.
2. The spray or breeze.

3. Indirect sparks.
4. Direct sparks.
5. The static induced current.
6. Potential alternation.
7. The Morton wave-current.

74. General Electrification or Charge.—It was shown in Art. **34**, when the action of a condenser was explained, that the capacity of a conductor was greatly increased when it was placed near a conductor electrified with the opposite kind of charge. This static induction is generally the phenomenon made use of when a patient is connected with a static machine. In general electrification the subject *M* is placed on a platform *P*,

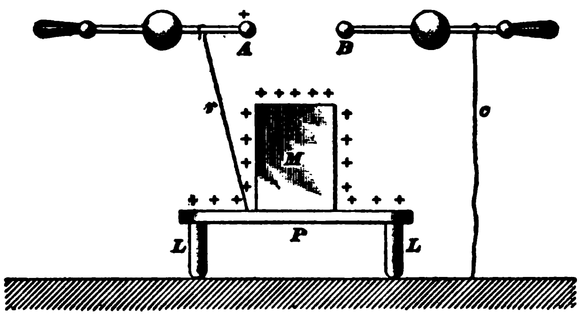


FIG. 33.

Fig. 33, and the platform connected with one of the prime conductors *A B* of the machine by means of the rod *r*. As the platform rests on glass legs *L* it is completely insulated from the ground and whatever charge is sent through the rod *r* should, under proper conditions, remain on the platform and the patient seated on it. In fact, we may consider the rod *r* with subject *M* as a simple continuation of the conductor with which it is connected.

We will suppose that in this case connection has been made with the prime positive conductor *A*. The platform receives a positive charge and the subject is said to be under **positive electrification.** The negative prime conductor *B* is grounded by connecting it to a gas- or water-pipe by means of a wire or chain *c*. We have now a condition very similar to that illustrated by means of Fig. 18. Positive charges pass from the machine to the platform and patient, which together practically constitute the inner coating of a Leyden jar. The walls and surrounding objects make up the outer coating, while the intervening air is the dielectric. All around negative charges are attracted and bound by the positive charge on the patient, and the potential of these charges will increase until the platform has attained the maximum potential the static machine is capable of producing. If air were a perfect dielectric this would be the end of the procedure and no more charges could be sent to the platform; but various causes contribute to modify these conditions. Air in general is more or less moist and mixed with particles of dust; it is in constant motion. Further, while a solid dielectric would be more or less unaffected by the surface conformations of the charged objects, this is not the case with air. Prominent parts, whether round or pointed, assume a higher potential than adjoining level surfaces, and this increase of potential results in charging the surrounding air to such an extent that it is strongly repelled and constantly replaced by new layers of air. Positive charges are therefore continuously carried away from the patient by convection, and the more readily so because the dust and moisture of the air add very materially in promoting the leakage. We see, therefore, that the requirements for maintaining a static charge are not fulfilled, but that, on the contrary, the conditions are very unfavorable, if this is the purpose in view. A true static charge we may compare with a vessel filled with water. A charge that is constantly leaking away would correspond to a sieve receiving a continuous supply of water sufficient to maintain its surface level at a constant height above the bottom. The body of water is here continually renewed and a current of water is passing through the sieve, the rapidity of the flow depending on the rate at which the leakage goes on.

It is often remarked, as stated in Art. **30**, that static charges given to a patient no longer comply with the laws of static electricity. The apparent difference in this case is not the result of a change in the nature of static electricity when applied to the human body, but is caused, as shown above, by not complying with the conditions necessary to maintain a static charge. In fact a patient who is situated on an insulated platform and continuously supplied with fresh electric charges that are at once disseminated into space, as convective charges, cannot properly be said to be in possession of a static charge, but must, on the contrary, be traversed by an electric current. The rate at which this current flows will depend on the rate at which the leakage takes place. How deep this current penetrates the interior has also been a debated question. In many cases the density of these currents through the body would vary, because the latter is made up of so many varieties of materials differing in conductivity. Some of these act more as insulators while others conduct the current very freely.

When the connections between the patient and the static machine are reversed so that the negative pole *B* of the latter

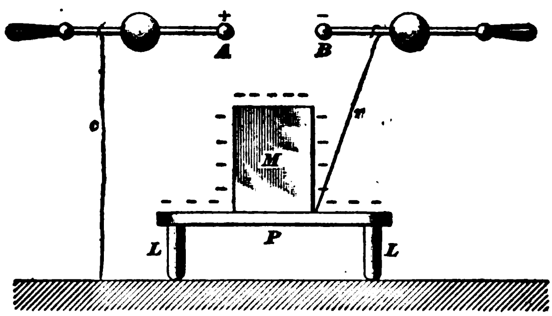


FIG. 34.

is connected with the platform, then we have what is called **negative electrification.** This combination is represented by means of Fig. 34. The positive conductor *A* is now grounded by connecting it through chain *c* with the ground.

75. The Spray or Breeze.—The spray is in reality nothing but an intensification of the leakage at some special point or surface. For a **positive breeze** the patient is placed as shown in Fig. 35. The platform is connected to the negative conductor *B* by means of the rod *r* and the positive conductor *A* grounded through chain *c*, which is connected with the outside layer of an imaginary Leyden jar. The patient and platform are negatively charged, and the surrounding walls, etc., positively. The aim is now to give these positive charges opportunity to discharge themselves by convection towards some definite place of the patient's body. For this purpose a supplementary conductor *E* is brought in communication with the

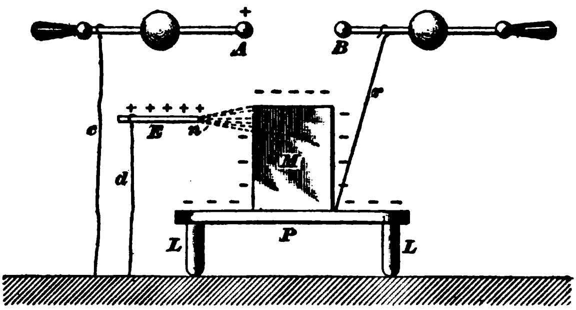


FIG. 35.

ground by means of the chain *d*. By induction, charges of a high positive potential are drawn into conductor *E* and, if the latter is provided with a number of needles *n*, convective *positive* charges are sent towards the patient, causing a strong current of air. Whether this discharge is a *breeze* or *spray* depends on the

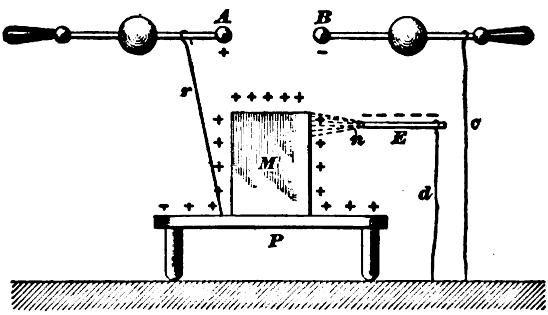


FIG. 36.

proximity of the electrode *E* to the patient. If not too near, an electrified current of air will pass from it, which is called a *breeze*. If near enough, a shower of fine sparks will be sent towards the patient; it is then a *spray*. The electrode *E* may be stationary or moved by the operator so as to affect larger areas.

To give a **negative** breeze, connections are made as shown in Fig. 36, giving the patient a positive charge and inducing a negative one in the electrode *E*. A negative breeze is therefore sent towards the patient.

76. Indirect Sparks.—By substituting a ball electrode for that of the needle electrode, the potential of the charge,

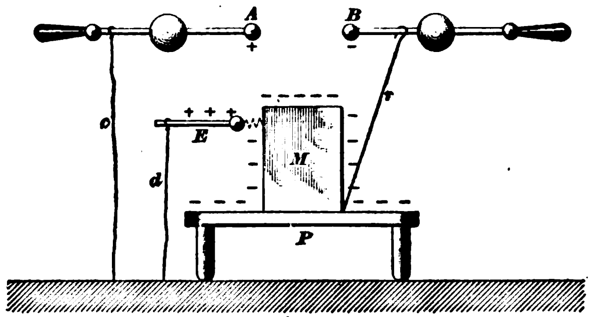


FIG. 37.

induced in the latter, will increase beyond that required for a convective discharge, and will be raised sufficiently high to produce sparks when brought near enough to the patient.

The connections to be made between the patient and the

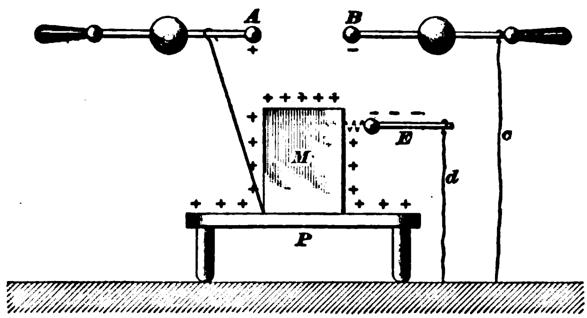


FIG. 38.

machine are the same as those made for the static spray. In Fig. 37, **positive**, and in Fig. 38, **negative**, sparks are sent to the patient.

It will be seen that in this arrangement the sparks do not proceed directly from the machine but indirectly through the ground, thereby utilizing the induced charges on the surroundings. The result is that the sparks are large in volume and more regular.

77. Direct Sparks.—When the direct spark is given, neither of the prime conductors are connected with the ground

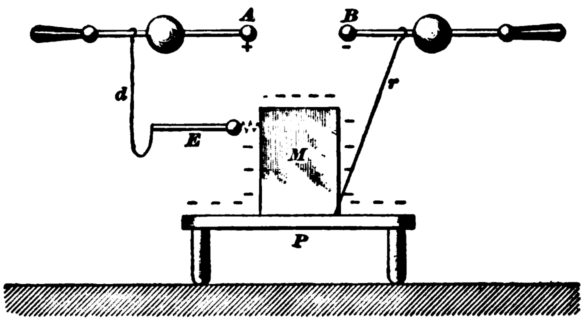


FIG. 39.

and the sparks will therefore be thinner and more uneven. Fig. 39 indicates the arrangement for giving **positive sparks.** The subject *M* with platform is joined to the negative prime conductor *B*, while the electrode *E* is electrically connected to

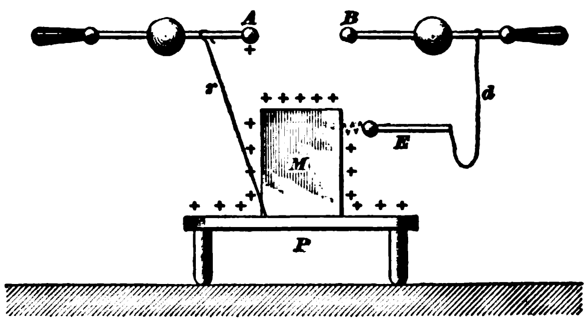


FIG. 40.

the positive conductor *A*. Fig. 40 indicates the connections for giving the **negative spark.**

In analyzing the effects of both the direct and indirect sparks on a subject, we find that previous to the discharge he is subjected to a rapid rise of potential, which, when the spark passes between him and the electrode, he suddenly loses. The spark itself is usually made up of oscillating charges and the patient is, therefore, for the time being, traversed by extremely rapid surges of electric charges throughout the body.

Both when giving direct or indirect sparks, the latter will increase in volume if the inner coatings of two Leyden jars are connected to the two prime conductors while the outer coatings are brought in direct communication with each other by means of a conducting-cord. By this arrangement charges of high potential are bound on the inside coatings of either jar, which will be released whenever a spark passes between subject and electrode.

78. The Static Induced Current.—This combination of a static machine with Leyden jars, made for the purpose of

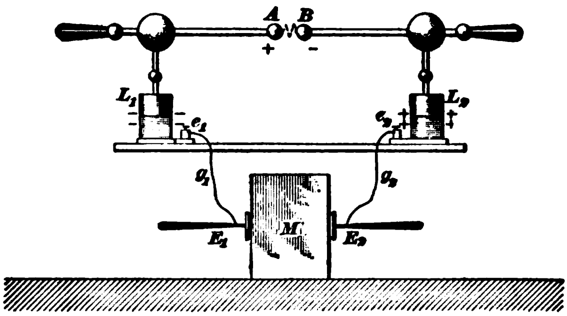


FIG. 41.

producing an alternating current, was first suggested and used by W. J. Morton, M.D., in 1880. The Leyden-jar arrangement mentioned in the previous article is again made use of in the manner illustrated in Fig. 41; but instead of bringing the outer coatings in direct communication with each other as in the former case, the body of the patient is also included in same. The prime conductors A and B are brought in electric connection with the internal coatings of the Leyden jars L_1 and L_2. The external coatings are connected with the binding-posts e_1 and e_2, to which the conducting-cords g_1 and g_2, with electrodes E_1 and E_2 may be attached. Though the subject is usually, as in this case, placed on the insulating platform, it is not necessary because it is here not a question of static insulation, but of local alternating currents.

Let us suppose that small positive charges are constantly sent from conductor A into the Leyden jars L_1, and negative charges from conductor B into Leyden jar L_2, and that the air-gap between A and B is great enough to prevent the charges from uniting at once. The charges on the inner coating of either jar will bind charges of opposite polarity on the outer coatings. Thus the jar L_1 will have an outside bound negative charge and L_2 a bound positive charge, while free positive charges will continue to flow through conductor g_1 and unite with free negative charges coming through the other conductor g_2.

This charging of the jars will continue until the difference of potential between the inside charges of the two jars has reached such a value that it is able to overcome the resistance of the air-gap $A\ B$ and bridge it by means of a spark. Under ordinary conditions this disruptive discharge between the prime conductors will be oscillating, and the following will take place: A positive charge will rush from A to B tending to neutralize the negative charge on the latter and its Leyden jar, but the self-induction of the circuit causes an excess of current to go towards B and charges the latter with jar L_2 positively. As soon as the current has come to rest it will again seek to equalize the difference in pressure by rushing back to A and L_1. The self-induction will now cause an excess of current to go in this direction and another reversal will take place, and these reversals will continue until a final balance has been restored. The intervals between these spark-discharges will, as previously explained, depend on the capacity of the jars, the length of the air-gap, the size of the revolving plates, and the speed at which they revolve. The frequency of these oscillations may, when a patient is in the secondary circuit, be from 200,000 to 300,000 cycles per second.

We have here an arrangement that has some similarity to an induction-coil in so far as the circuit $g_1 M g_2$, which may be called the secondary circuit, is insulated from the primary circuit, which consists of the inside coatings of the Leyden jars L_1, L_2 with conductors A, B.

79. Potential Alternations.—This method of producing an alternating current of high frequency by means of a static machine may be said to be a variation of one of the spark-gap arrangements suggested by Morton in 1890, and first used by Dr. S. H. Monell in 1893. The difference being that while Morton uses a hand-electrode with a variable spark-gap, Monell uses a separate stand with a supplementary ball-electrode.

It will be seen from Fig. 42 that the arrangement of parts is practically that of Fig. 33 for producing positive electrification. The difference between them is that in Fig. 42 a spark-gap is introduced in the circuit by adding a supplementary conductor. The arrangements of parts is indicated in Fig. 42, where *S* is a

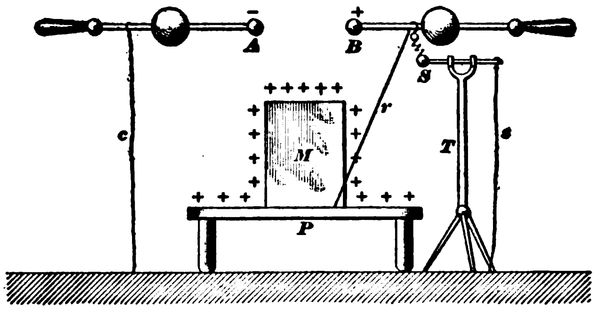


FIG. 42.

ball-electrode held firmly in position on the stand *T* and grounded by means of the chain *s*. The distance between *A* and *B* is made large enough to prevent any spark-discharge between them, while on the other hand the ball-electrode *S* is brought near enough to the hooked end of rod *r* to permit sparking to take place. The negative pole of the machine is grounded and the subject *M* on the platform given a positive charge.

We may explain the effect of this combination by supposing the platform with subject, to be charged positively, until the pressure is large enough to overcome the resistance of the air-gap between *r* and *S*, when the positive charge will suddenly pass to the ground through the chain *s*. The platform with subject may, while in possession of the positive charge, be considered as the interior coating of a Leyden jar; the surrounding walls, etc., the exterior coating with a negative charge; and the air, the dielectric. Whenever a discharge takes place, the positive and negative charge will unite through the ball-electrode *S* with chain *s*. This discharge will ordinarily be oscillating, and the subject *M* will therefore be traversed by an oscillating current whenever a spark passes to the ground. As these sparks follow each other in rapid succession, the effect may be said to be continuous. The current resulting from this combination is of less intensity than that produced by the static induced current method.

80. The Morton Wave-Current.—The arrangement for producing this current was suggested by W. J. Morton, M. D., in March, 1899. It produces the same effects as those obtained

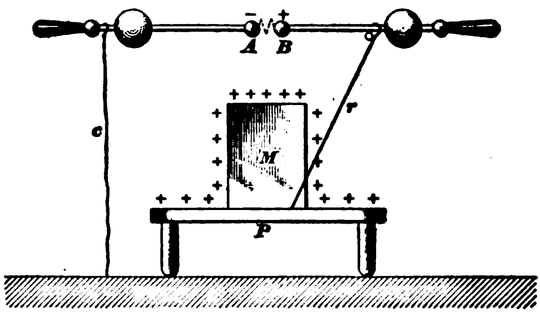


FIG. 43.

by potential alternation, but by simpler means. Doctor Bordier, in comparing the wave-current with the static induced current says: "These two modes differ, then, practically very little; that which distinguishes the old static induced current of Morton from the new current of Morton is principally in the strength of the effects in consequence of the much larger charge in the first disposition of parts."

It will be seen from Fig. 43 that the arrangement of parts is practically that of Fig. 42. The difference between them is that in Fig. 43 the supplementary ball-electrode *S* has been omitted and the spark-gap made between the prime conductors

A and *B*. The platform and subject are again connected to the positive pole *B* by the rod *r* and the negative pole *A* grounded through the chain *c*. Whenever the potential of the charge on the subject is high enough it will bridge the gap at *A B* by means of a spark and pass directly through conductor *A* and chain *c* to the ground. Otherwise the effects are the same and the potential of the charge may in this and the previous arrangement be modified by regulating the length of the spark-gap.

After the student has considered these seven varieties he will see that they may be separated in two main groups, as follows:

I. In the first group come those methods where an air-gap exists between the *subject* and an auxiliary conductor over which gap the static charges must pass in order to complete their circuit. The length of the gap will determine whether the application is "general electrification," breeze or spray, and indirect or direct sparks. This air-gap attains its maximum in "general electrification" and its minimum in some of the spark applications.

II. The air-gap is *not* between the subject and any auxiliary conductor, but somewhere else in the circuit. Under this division come the static induced current, the Morton wave-current, and potential alternation. The modalities included in this class come in reality in that of high-frequency currents, but as they were used before these currents were applied therapeutically, they will be retained in their present position.

HIGH-FREQUENCY CURRENTS.

81. General Characteristics of High-Frequency Currents.—Under frequency, as explained in *Direct Currents*, we understand the number of complete cycles that an alternating current performs per second. High-frequency currents would therefore simply mean alternating currents of high frequency. Distinction is made between these and alternating currents of ordinary frequencies, because there is quite a gulf between the frequencies of the two, and results are obtained by means of the high-frequency currents that are beyond the capacities of the alternating current, as generally found. It is also a peculiarity of these currents that while the human body may be very painfully affected by alternating currents of relatively low frequencies, currents of high frequency may be sent through the body and produce only a mild sensation. The reason for this is not definitely determined, but it seems that the sensory nerves are unable to respond to the rapid oscillations of the current, and though the body may be traversed by powerful currents, that under ordinary circumstances might be fatal, the senses do not seem to perceive them and they appear harmless.

82. Production of High-Frequency Currents.—An apparatus that may produce high-frequency currents is shown in Fig. 44. *I* is an induction-coil whose primary coil is supplied with a direct interrupted or an alternating current through the conductors *p* and *n* from any convenient source, the main purpose being to produce an alternating current of a high electromotive force in its secondary coil. The terminals of the secondary coil are not shown, but they are supposed to be connected directly to the posts *a* and *b* through which the rods *c* and *d* can slide so as to make any desirable spark-gap at *G*. The internal coatings of the Leyden jars C_1 and C_2 are also connected to the posts *a* and *b*, while their external coatings are brought in communication by means of the solenoid *S*. The Leyden jars are placed in metal sockets that communicate with their external coatings and have binding-posts *e* and *f* to which the solenoid is attached.

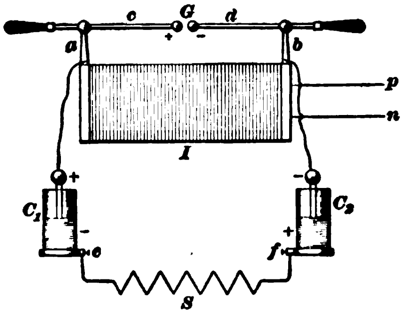


FIG. 44.

It has been shown previously that when using a direct interrupted current a maximum E. M. F. is induced in the secondary coil at the break of the primary current. As the primary current is then flowing only in one direction it follows that this maximum electromagnetic impulse that periodically is sent through the secondary coil, when the primary circuit is broken, must always move in the same direction. As the spark at G is not allowing any other current to pass except the waves due to this high E. M. F., it follows that these waves all begin to pass across the gap from the same side. When the primary coil is operated by an ordinary alternating current, then the impulses in either direction will be equal, and the secondary coil will also be traversed by an alternating current. An ordinary commercially supplied alternating current has a frequency of about 124. There would therefore be 124 positive and 124 negative waves per second, in all 248 waves that each would produce a spark at the gap G. To produce the same effect by means of a direct current the latter would have to be interrupted 248 times per second. In this instance we will suppose that the rod c is connected with that terminal that is in possession of a maximum positive potential before the spark-discharge has begun.

The rod c is therefore marked as being positive and d as negative. While the positive impulse now is moving along c tending to produce a spark, it will simultaneously enter the Leyden jar C_1 and give the inner coating a positive charge, thereby inducing a negative charge on the outer coating. At the same time the rod d, with the inner coating of the jar C_2, is given a negative charge with a positive charge induced in the outer coating. While the two jars are being charged there is simultaneously a current made up of the free outside charges flowing from the external coating of C_1 towards that of C_2. This current is only preparatory to the final discharge and is not directly of any importance.

When the difference in pressure of the Leyden-jar charges has reached a value high enough to overcome the resistance of the air-gap G, then the charges in the inner coatings will unite by means of a spark across the gap. For the reasons already given, the surplus charge of C_1 will not simply go over to C_2 and stop there, but will rebound a number of times between the jars before its energy is finally expended, whereby the difference of potential between the charges in the two jars will grow smaller until it finally reaches zero.

83. Graphical Representation of High-Frequency Currents.—This gradual decrease and periodic change of potential may be represented by means of Fig. 45, which refer to the changes that take place in the jar C_1. At c_1 we have the maximum potential of the charge before a discharge occurred; then it is seen that the pressure instantaneously not alone falls to zero, but to a maximum negative pressure at c_2. At this point the other jar has the charge of maximum positive potential, and when it returns from there the potential in jar C_1 is raised to the value of c_3, which is lower than the preceding c_1. It is seen that the potential of the charge gradually diminishes until it finally reaches zero. Similar changes go on in the other jar, alternating with those in the first.

It may seem strange why it should require a potential of c_1 (Fig. 45) to cross the air-gap, and that later on, charges of

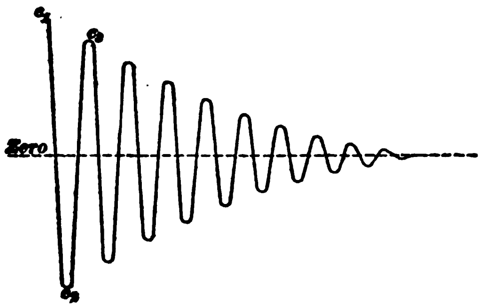


FIG. 45.

constantly decreasing potential still should be able to cross the gap. The reason for this is that after a spark has once passed, the resistance across the air-gap has been greatly reduced, thus allowing charges of much lower potential to pass.

The outside charges on the Leyden jars are in this instance the source of the high-frequency currents. As soon as the inside charges are released and begin their oscillations, the outside charges are also free, and, as the latter are of the same potential difference as the former, the same kind of oscillations will be carried on in the exterior circuit S, but in a reverse order. Thus, when the interior charge passes from C_1 to C_2, the exterior charge will pass from C_2 to C_1.

As each spark consists, relatively speaking, of only few oscillations, it follows that if a continuous series of such oscillations are to be maintained, the induction-coil I must be capable of constantly supplying the Leyden jars with fresh charges.

84. Their Current-Strength.—Before explaining the methods of utilizing the high-frequency currents passing through the solenoid S it may be well to call attention to some of the peculiar characteristics of these currents. For instance, it seems strange that the small electric charges contained in the Leyden jars should be able to produce so strong effects, but it must be remembered that it is not alone the quantity of electricity passing through a conductor that determines the effects, but also the rate at which it flows. For instance, when 1 coulomb of electricity is flowing through a conductor per second, the rate of flow is said to be 1 ampere. When the pressure is raised to such a value that this quantity of 1 coulomb could pass through the conductor in $\frac{1}{1000}$ second, the rate of flow would be 1,000 amperes, and if the passage were accomplished in $\frac{1}{1000000}$ second the current would have a strength of 1,000,000 amperes. Of course, currents of high frequency are only of short duration and they are alternating, otherwise they would not alone be intolerable, but also dangerous to life.

85. Induction Effects.—Another characteristic of the high-frequency currents is the intense effects they produce by means of induction. It was shown in Art. 76, *Magnetism and Electromagnetism*, that it is not alone the current-strength in the primary coil and the number of turns it contains that determine the E. M. F. in the secondary coil, but also the rate at which the current is interrupted or changed in direction. For instance, let a primary coil be made up of 1 turn of wire in which circulates an alternating current of 1 ampere with a frequency of 500,000. The effect of this coil on an adjoining solenoid would be the same, when no other changes have been made, as if 100 amperes were passing through a primary coil of 100 turns at a frequency of 50, as the effect on the secondary coil depends on the product of current-strength and frequency in the primary coil. This is the reason why one single turn of wire held near a solenoid carrying high-frequency currents may show such surprising effects, as, for instance, to light an incandescent lamp requiring a current of 1 ampere and 8 volts.

86. Effect of Capacity.—Perhaps the most striking effects produced by currents of high frequency are those caused by the capacity of the circuit. This may perhaps be better understood by taking an analogy from some other branch of physics. For instance, let *a* in Fig. 46 represent a cylinder in which air may be compressed by means of the piston *d* and sent through the tube *b* into the rubber ball *c*. It is clear that the more capacity this ball has the greater quantity of air may be forced into it before the compressing piston in *a* will have to come to a standstill. By allowing the piston again to return to its starting position the air in *c* will expand. By repeating

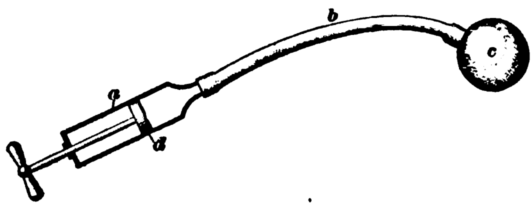


FIG. 46.

these operations of forcing the piston inward and letting it return, a current of air will oscillate through the tube *b*. If the available pressure on the piston remains constant, it is clear that the more elastic and capacious the ball is the more air will it receive at each stroke, and the greater will be the current-strength through *b*, even when the number of piston strokes per second is relatively small. Let, now, the ball *c* be removed and we will simply have the capacity to deal with that the tube *b* itself may be in possession of, which would be very little, and the distance through which the piston could be forced inward would therefore be very small. If it is desirable, still, to maintain the same current-strength through *b*, other means must be found. Let, for instance, the piston be operated by some motor that is able to exert a greater pressure and at the same time perform a high number of oscillations per second. It is then possible that though the quantity of air forced out of the cylinder at each stroke may be small, yet by reason of the great number of these impulses, the combined quantity per second may amount to the same as that forced out of the cylinder when the ball *c* was included in the circuit. The reasons for this are the same as those given in Art. 84.

87. The Condenser Electrode.—Looking at the condenser effects produced by high-frequency currents in this light they may appear less mysterious, in particular when it is remembered that these currents are not alone of high frequency, but also of high pressure. The principle underlying all these phenomena, where a capacity comes into play, is simply that

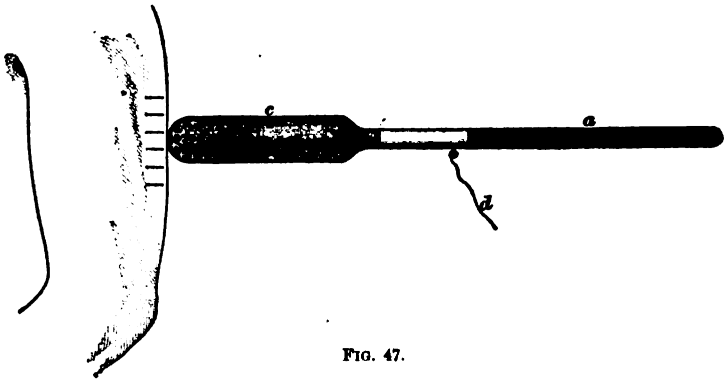


FIG. 47.

of the Leyden jar, as explained by means of Fig. 44, and in other places. Let this be illustrated by an example taken from the application of high-frequency currents. Fig. 47 represents an electrode used for skin-treatment by these currents. The current is sent through the conductor *d* through the binding-post *b* into the interior of the glass cylinder *c* that is filled with fine graphite powder or has an interior coating of tin-foil. The handle *a* is made of hard rubber and acts as an insulator for the operator's hand. Let it be supposed that a wave of positive potential is sent into the graphite, that in this case corresponds to the interior coating of a Leyden jar. The glass cylinder *c* plays the role of the dielectric while that part of the skin with which the electrode comes in contact may be considered as the exterior coating of the Leyden jar. The momentary positive charge will induce a negative charge on the exterior coating and a current-impulse of negative potential will move through the tissue towards the tip of the electrode. When the current reverses its direction the interior of the electrode will be negative and a positive charge will be induced in the adjacent tissue. The same phenomenon meets us again here, viz., a relative small charge alternating in potential at a high frequency, and thereby inducing currents of relatively high amperage in surrounding tissues. The remarkable feature about this phenomenon is that a current is produced, though there in reality is only one electrode and apparently no complete circuit. But after the explanations given by means of Figs. 46 and 47, the reasons should be clear. It should be added that in practice this electrode rarely is in direct contact with the skin. There is usually a space of about 1 to 4 millimeters between electrode and skin, and numerous violet sparks are seen to pass across the intervening space. By increasing the distance the sparks will decrease in number but increase in intensity.

88. Resonance Effects.—One more striking characteristic of high-frequency currents is their resonance effects. A consideration of these would rather go beyond the scope of this paper, and a few remarks on this subject must suffice. When a piano string of a certain length and diameter is set into vibration it may, by reason of the phenomenon of resonance, cause another string to vibrate that is either of the same length and diameter, or a simple fraction or multiple of same. The effect on the second string is a cumulative one, that is, each impulse proceeding from the primary vibrating string adds to the vibration previously given the secondary string until a maximum is obtained, which is of less intensity than that of the primary string. What is called resonance in electric circuits is somewhat similar in its manifestations. For instance, if a charge is oscillating in a circuit of a certain capacity and self-induction, the ether-waves proceeding from it will cause electric charges to oscillate backward and forward in another circuit that is either of the same kind or bears a certain simple relation to it. The impulse imparted will at first be very weak, but by always arriving at the right moment the effect will also here be a cumulative one, until at last the energy received may be large enough to show its presence by causing a discharge across an air-gap in the circuit by means of a spark.

89. Utilization of High-Frequency Currents.—We are now in a position to consider the apparatus by means of which the currents of high frequency are either produced or utilized.

There are three methods by means of which these currents may be applied—that of condensation, auto-conduction, and local application.

1. *Condensation.*—In either of these methods the induction-coil, as described in Art. **82**, forms the foundation. It may be

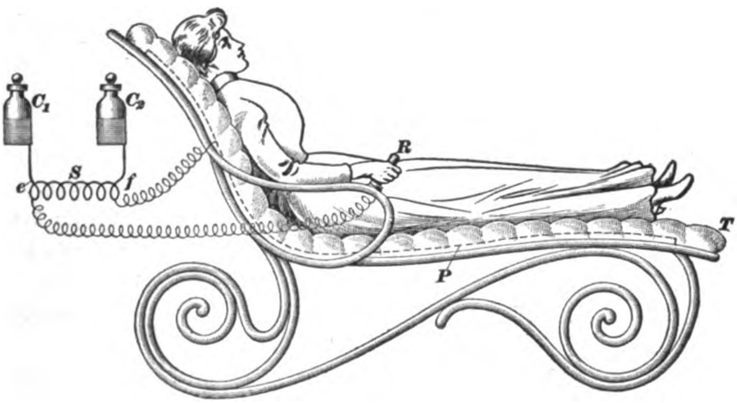


FIG. 48.

operated by an alternating, or by a direct, current, with an interrupter in circuit. Static machines may also be used for these applications, but do not give as uniform results and are not as reliable.

When applying high-frequency currents by means of condensation, the patient is usually placed on a lounge, as shown in Fig. 48. Between the lounge proper and the cushion *T* is inserted a metal plate *P* that is connected with one end of the solenoid *S*, while the other end connects with the handles *R*, one of which is shown, or it may be joined to a plate against which the patient's feet may rest. The solenoid with Leyden jar are here simply diagrammatically represented, the connection with the other parts being omitted. The combination of patient and lounge practically constitutes a Leyden jar in which we may assume the patient, for instance, to be the inner coating, the cushion *T*, the dielectric, playing the role of the jar itself, and the plate *P* the outer coating.

To properly understand the phenomenon, the student should bear in mind that there is the same difference in potential between the two ends *e* and *f* of the solenoid as there is between the Leyden jars C_1 and C_2, so that if the end *e* for the time being has a maximum positive potential the end *f* would be negative. The handles *R* with patient would therefore also be positively charged while the plate *P* would be negative. As soon as the Leyden jars change polarity, patient and plate will do the same, and the result will be that the patient is constantly subjected to a back and forward surging of electric charges of high potential and frequency.

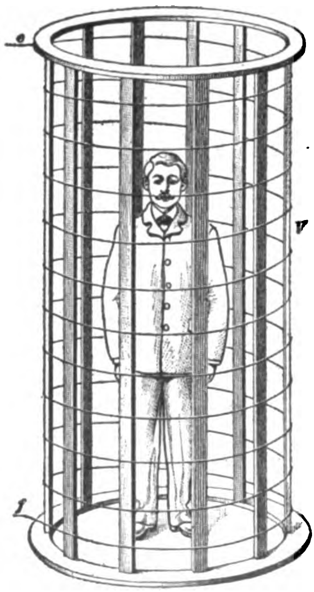


FIG. 49.

2. *Auto-Conduction.*—The phenomenon utilized in this method is somewhat different. In its elementary form we may suppose the large solenoid *V*, shown in Fig 49, to have its two extremities connected to the solenoid *S* in Fig. 44. The solenoid *V* will then be traversed by currents of high frequency, and intense inductive effects will be produced in the space surrounded by it. If, then, a patient is inserted in the coil, as indicated in the illustration, he will be subjected to those inductive influences, and heavy currents of high frequency will

surge through his body in directions parallel with those of the inducing current.

3. *Local Application.*—For local applications of these currents, either *Oudin's resonator* or *D'Arsonval's* improved bipolar high-tension coil are utilized. The fundamental form of the resonator is shown in Fig. 50. The function of this coil is based on the phenomenon of resonance mentioned in Art. 88, otherwise the apparatus is very similar to that illustrated in Fig. 44,

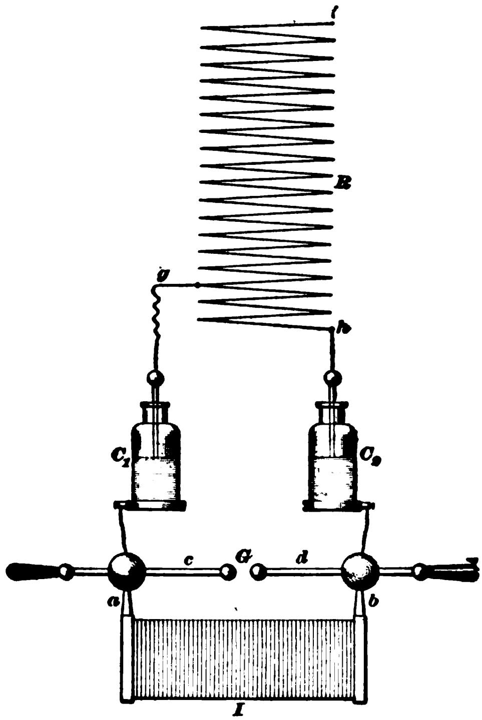


Fig. 50.

the difference being that only part of the solenoid is included in the Leyden-jar circuit, the remainder being acted on partly by resonance and partly by induction. In Fig. 50, the part marked *g h* is that traversed by Leyden-jar currents. The other part *g i* acts as the resonator proper. In order to be able tentatively in finding the proper relation between the two coils, the conductor at *g* is so constructed that by means of a clamp or contact the number of turns included in the primary coil *g h* may be adjusted so as to give a maximum effect in the secondary coil *g i*, which will show itself by the appearance of a convective discharge at *i*. At this point the conducting-cord that leads to the patient's electrode is attached and effects produced that were illustrated by means of Fig. 47.

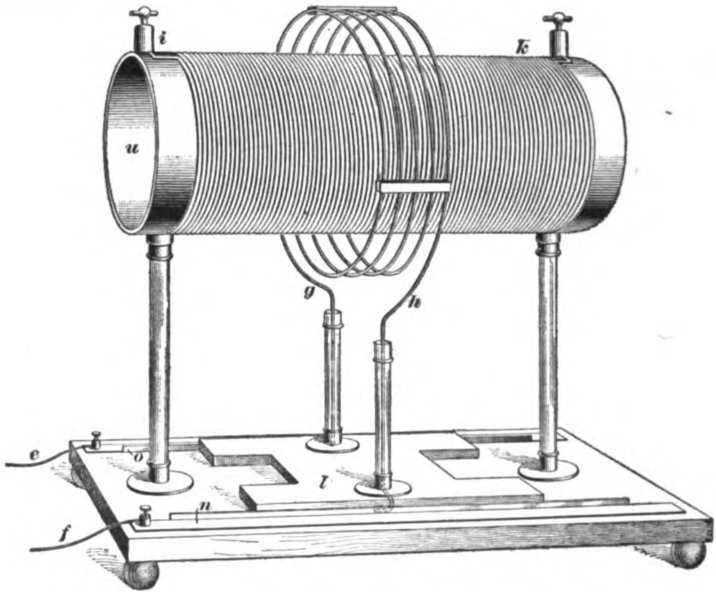


Fig. 51.

The D'Arsonval bipolar high-tension coil is illustrated in Fig. 51, in which *g h* represents the primary coil of coarse wire, and *i k* the secondary fine-wire coil wound on the drum *u*. Communication is established between the coil *g h* and the Leyden-jar circuit *e f* through the metallic guides *n o* with which the primary coil makes a sliding contact. To the binding-posts *i k* are attached the conducting-cords for the electrodes. When the primary coil *g h* occupies the position indicated, the effluvious discharges will be evenly divided at each electrode; but this discharge may be limited either to the left or the right binding-post and electrode by moving the primary coil either to the right or left. In that case the active electrode is applied to the desired place and the other used either as an indifferent electrode or grounded.

A recent variation of the D'Arsonval apparatus is shown diagrammatically in Fig. 52. The induction-coil I with spark-gap G and Leyden jars C_1 and C_2 are arranged as previously explained. From the outside coating of Leyden jar C_1, connection is made with the primary coil S of coarse wire that

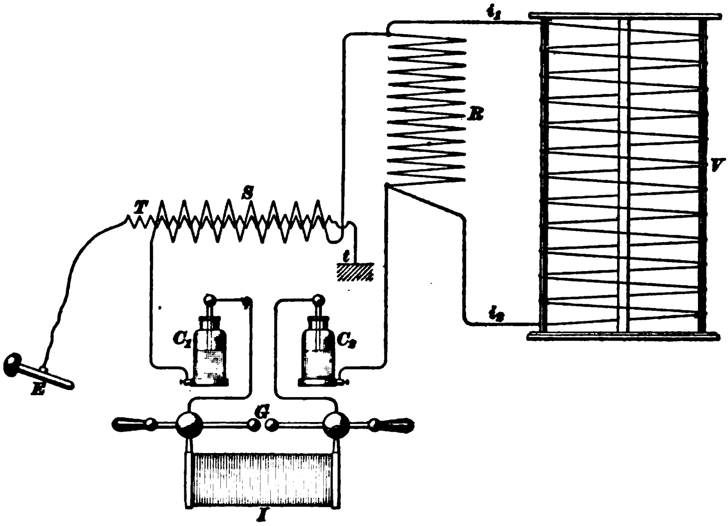


FIG. 52.

again connects with the resonator R. The auto-conduction coil V may be brought in communication with the resonator either by means of one of the conductors i_1 or i_2, or by both jointly. In the primary coil S is a secondary coil T with about 5 times more turns, that will give a current of higher E. M. F. One end of this coil is connected with the electrode E and the other with the ground at t. This electrode can also be connected to any of the turns in the resonator R by means of a spring clamp. By selecting the proper place, weak or strong currents may be obtained, depending on how near or far the clamp is to its connection with the primary coil.

90. Electrodes.—The electrodes utilized for applying high-frequency currents are of three kinds: Ordinary metal electrodes, condenser electrodes, and vacuum electrodes.

The *metal* electrode is simply a metal button or ball, elongated or broadened, as circumstances may require, and provided with an insulating handle.

Condenser electrodes have already been explained. Any variation in their form may be made so as to adapt them for external or internal use, or for action on a broader or more limited area.

The *vacuum* electrodes consist of an elongated glass tube with a low vacuum and provided with one terminal only. A reddish or bluish stream is noticed in the interior when connected to the conductors of a high-frequency coil, depending on the condition of the vacuum. When contact is made with the electrode, the stream is seen to direct itself to the point of contact, and the usual display of sparks is noticed on the external surface of the electrode.

ACCESSORY APPARATUS.

APPARATUS USED FOR CONTROLLING AND MEASURING.

1. Introductory.—In this section the various apparatus required in the application of the direct, faradic, and sinusoidal currents will be considered. It may, therefore, to many students appear to be the most important one, and they may perhaps be of the opinion that the previous subjects are of secondary importance to the present one. Of course, the prospective benefits to be received from the practical application of any knowledge obtained is always the main end in view; but a requirement of prime importance, and which must first be complied with, is that the knowledge gained is not of a transitory nature but thorough and lasting. We wish, therefore, to say at this point that it is not sufficient to have read the previous sections understandingly and answered the questions correctly. A subject such as electricity, that is so different in its laws and manifestations from other phenomena daily met with, cannot possibly be properly digested and assimilated at one reading. It needs reconsideration and reviewing again and again, when new light will gradually be thrown on many questions that at first appeared very simple and elementary. One will little by little learn to see their importance and wide application in numerous cases and varying conditions.

As the one subject of prime importance we wish to call attention to Ohm's law in all its variations. So simple as this law appears at first glance, so surprising is it to the student, by degrees, to discover its wide scope of usefulness in all electrotherapeutic treatments. The physician should, therefore, be as familiar with it as with his multiplication table. By this, we do not mean a simple memorizing of it in its three forms, but constantly to have it in mind and apply it to the variations that may be accomplished in any electric circuit; be it with a patient in the circuit, or an arrangement of electric devices subject to the action of the current. Some of these applications will be explained in the following pages, but there are numerous others that the physician may find among his daily experiences.

Regarding the theory of the various apparatus given in the previous pages, which to some students may seem more or less superfluous, we may say that if it were not of importance to know the fundamental principles on which the action of the several appliances depend, it would greatly simplify the study of electricity, as far as electrotherapeutics is concerned. A simple description of how to use the different devices would then fill all requirements. The physician would then occupy the not very enviable position of that of the general public with reference to the numerous patent medicines offered in the market. In both cases, it is a blind faith in means about the nature of which one is ignorant.

It should also be remembered that these sections do not alone serve the purpose of imparting necessary information, but serve also the additional purpose of placing the student in a position in which he is able to acquire additional information and to follow up the progress that is made in his branch. To work intelligently and with the best results the practitioner should not alone know what he is doing and wherefore, but should also be able at any time to step out of the beaten path of his regular routine work to make independent investigations and at the same time be able to interpret the results correctly.

2. Scope of this Section.—In the present section will be considered the steps necessary to regulate the current-strength that is available from any source at hand either by means of a cell-selector, or rheostat, or both in conjunction; also, instruments that will record the pressure and strength of the current that passes through the patient, electrodes as means for directing the current to the desired part of his body, and the hydraulic bath, in which a certain quantity of water serves as an electrode either covering part of or the whole body. To complete the information about sources of electric pressure, the dynamo is considered in its general features; finally, apparatus that serve as motors for running static machines and devices such as centrifuges, etc.

APPARATUS USED FOR CONTROLLING THE CURRENT STRENGTH.

CELL-SELECTORS AND RHEOSTATS.

3. Purpose of Cell-Selectors.—When a voltaic battery is used as a means for supplying the galvanic current to a subject, it consists usually of a large number of cells, as for instance 40 or 60, in order to provide the necessary voltage when currents of greater strength are required. It is very likely that the whole battery is used only on rare occasions, and that more frequently merely a small part of it is put in action. In such instances, it would not only be inconvenient to constantly have to disconnect and reconnect the various cells, but it would also give opportunity for making wrong, as well as poor, connections. It is therefore preferable to have the cells connected up once and for all and to use other means for selecting the required number of cells, as the treatment at hand may require.

The cells are mostly connected in series, and it is, therefore, simply a question of including a greater or smaller number in this series. For this purpose *single-handed* or *double-handed cell-selectors* are used.

4. Single-Handed Cell-Selectors.—If the battery contains a small number of cells, then the **single-handed selector,** shown diagrammatically in Fig. 1, may answer the requirements. The letters E_1, E_2, etc. indicate the separate cells, while z, c stand, respectively, for the negative and positive elements of the same. The positive element of each cell is connected with the negative one of the preceding cell by means of wires c_1, except the positive element of the first and the negative one of the last cell, which communicate directly by means of wires c_2, c_3 with their respective studs d_0, d_6. The wires c connect the other studs to the cross-connections c_1, already mentioned. A is a plate of insulating material—as ebonite, slate, or hard wood—well varnished, in which the buttons d_0, d_1, etc. are inserted, and over which the lever, or hand, B is intended to move and establish contact. The hand B is pivoted on the stud B_1, which connects with the negative terminal

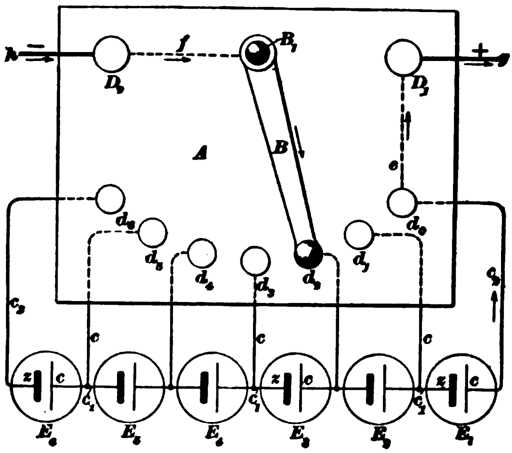


FIG. 1.

D_2 through the wire f. The other terminal D_1 is connected to the stud d_0 by means of the wire e. All these connections are, as indicated by the dotted lines, under the plate A and therefore out of the way, except the wires g and h, which connect the selector with the device upon which the electric current is intended to act.

In the present position of the hand, the first two cells E_1, E_2 are placed in action, while the remaining cells are out of circuit and inactive. If the hand B is placed on the stud d_1, the cell E_1 alone will be in action. It is thus seen that by moving the hand to the left, more and more cells will be placed in action, until, when the stud d_6 is reached, all the cells are included in the circuit.

The drawback inherent in this selector is the necessity of using some of the cells more than others. For instance, cell E_1 will be included in any combination, and will therefore be sooner exhausted than the rest; while E_6 will last the longest because less frequently used.

5. Double-Handed Selectors.—In the **double-handed selector**, as illustrated in Fig. 2, it is possible to use any num-

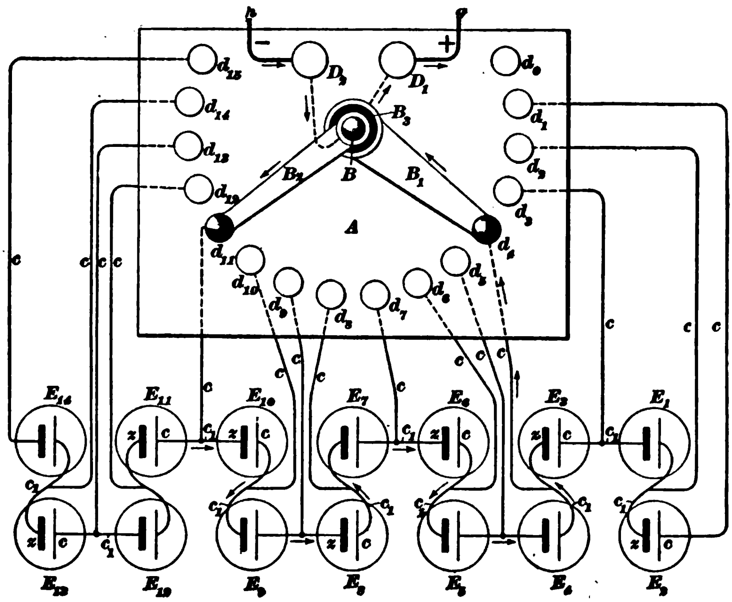


Fig. 2.

ber of cells in any part of the series, and to let these alone be acting, independently of the cells preceding or following in the series. By this means it is possible to use all the cells to the same extent. This is accomplished by the introduction of an additional hand B_2. The interconnections of the cells, and their connection with their respective studs are exactly the same as in the preceding figure. The new feature is found in the hands, one of which B_1 connects with the positive terminal

D_1, while the other B_2 connects with the negative terminal D_2. The two hands are insulated from each other by the ebonite bushing B_3; B_1 and B_2 revolve around the stationary stud B. There is an extra stud d_0, which has no connection with the cells; whenever the hand B_1 makes contact with this stud, the battery is on open circuit and no current will flow through the wires g and h. It is seen that if one cell only is required, it is just as easy to use the last as the first cell, in fact, any single cell can be selected. For instance, placing the hands on d_{14} and d_{15}, the cell E_{14} alone is in operation; while on making contact with d_7 and d_8 only the cell E_7 is in circuit. In either of the figures the arrows indicate the direction of the current from the negative to the positive terminals.

6. Selectors as Current-Regulators.—It is clear that these selectors will also serve as **current-regulators:** In Fig. 1, by placing the hand B on the stud d_1 and gradually moving it from stud to stud, and in Fig. 2, by letting the hand B_1 remain stationary on d_1 and moving B_2 over the studs toward the left. In either case, the E. M. F. will be increased, and, if the external resistance remains the same, also the current-strength. As the addition of one cell at a time will make the increase too great to suit electrotherapeutic purposes, a rheostat must be used in conjunction with the selector. This will enable the operator to give any desired current-strength intermediate between that of the two cells.

It is not always that every cell is connected with a stud; sometimes it is only every second or third cell. In that instance, the pressure is increased by two or three cells at a time. This is done when the number of cells is very great, in order to avoid too many connections.

7. Precautions to be Observed.—Care must be taken not to leave a hand between two studs in such a manner as to make a contact with both, as the cell that is inserted between these studs will be short-circuited and perhaps permanently injured. If, for instance, the hand B, Fig. 1, should be left between the studs d_4 and d_5, cell E_5 would be short-circuited, because the current could pass from d_4 through B and d_5 back to the cell. The two binding-posts of the cell would, in reality, be directly connected without any intervening resistance and the cell would quickly run down.

8. Objection to Cell-Selectors.—To install a battery of 50 or 60 cells with the necessary connections to the selectors is quite a task, as it requires a great many connections. The battery, very likely, is in another part of the office or building; it may therefore, for instance, require about 60 separate wires to connect the battery with the cell-selector. Then, again, in case any renewal of cells is required, it is not always easy for a novice to locate the trouble and repair matters himself. Finally, it requires a rheostat in conjunction with the selector to regulate the current-strength in all its minute variations. For these reasons, modern practice tends to dispense with the cell-selector and to regulate the current entirely by the *rheostat.*

9. The Rheostat.—When the **rheostat** is used for regulating the current-strength of an entire battery of voltaic cells, all the cells are simply connected in series and only the first and last binding-posts of the battery connected to the rheostat by means of two wires. This is illustrated by Fig. 3, which shows diagrammatically the cells, rheostat, and their connections. E_1, E_2, etc. represent the cells connected in series by means of connectors c, c. A is the wire rheostat with the two binding-posts D_1, D_2 to which the battery wires c_1 and c_2 are connected. B is the resistance coil proper that through wire d_1 is connected with the binding-post D_1. A lever G, which rotates around the stud k, makes a sliding contact with the coil B and is, through the wire l, brought into communication with the electrode binding-post E_1. The other binding-post E_2 is, through the wire d_2, brought into direct communication with the battery. The patient connects, through conductors g and h, with the rheostat. It is seen that the current from the battery passes at first through wires c_1, d_1 into the resistance-coil, and from there through lever G, through wires l and g, to the patient. The position of lever G will therefore determine how much resistance is inserted in the circuit, as the nearer it is brought to the end b_1 the less resistance is included; while the more it approaches the other end b_2 the more the resistance will increase. When, therefore, the lever stands at b_1, all the resistance is cut out and the patient receives the whole strength of the battery-current. If at b_2, the whole resistance is inserted and a current of minimum current-strength is delivered. It is seen that here the resistance is in series with the patient and that, therefore, the entire current that reaches the patient must first go through the rheostat. This has certain disadvantages, one of which is that the current-

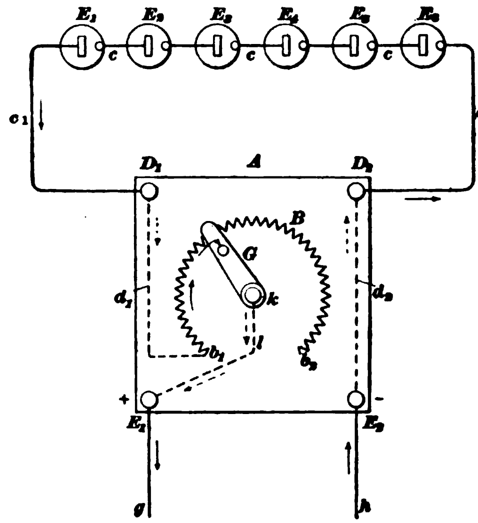


FIG. 3

strength cannot be reduced to absolute zero unless the resistance of the rheostat is very high; for this reason, and also to insure greater safety when the commercial lighting circuit is used in place of a voltaic battery, it is general practice to connect the patient in shunt with the rheostat. The subject of shunts has been explained in *Direct Currents*, but it requires some further elaboration here in order that the function of the shunt, when used for current regulation, may be better understood.

As the voltage of an electric current decreases as it passes along a circuit and overcomes the various resistances, it will now be shown how this variation in pressure, in combination with a shunt, will enable us to vary the pressure in a patient's circuit when connected with either a lighting or battery-circuit.

10. Hydraulic Analogy of a Shunt Rheostat.—Let the coiled tube *A*, Fig. 4, be supplied with a current of water that is subjected to a constant pressure. At certain intervals the coil is provided with faucets c_1, c_2, etc. to which the rubber hose *d* may be connected. The latter is supposed to supply

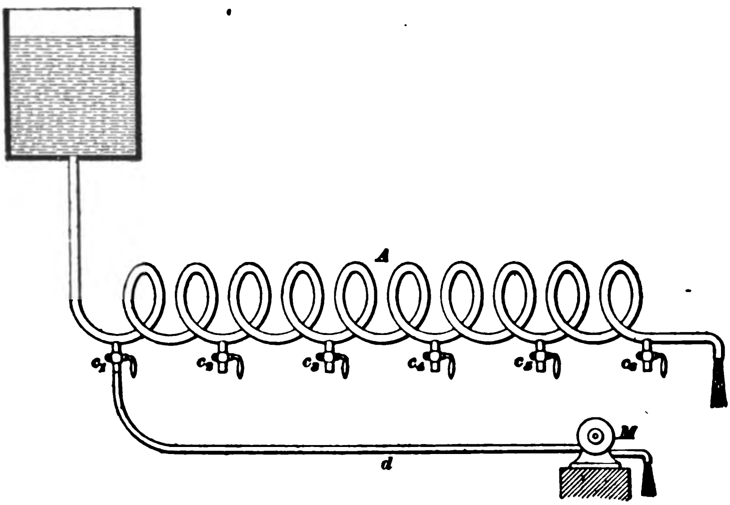


FIG. 4.

the hydraulic motor *M* with water under sufficient pressure for the power it may have to develop. Let it be supposed that the pressure at c_1 is 50 pounds per square inch, and that at each succeeding faucet there is a decrease in pressure of 10 pounds; the pressure at c_6 will then be zero. This loss in pressure is supposed to be caused by the friction of the water along the walls of the coils. It is now clear that we may select any desirable pressure between 50 pounds and zero with which to drive the motor *M* by simply connecting the hose to the faucet in possession of the necessary pressure. Water will then flow both through the coil *A* and tube *d* and they may be said to be in parallel, or that *d* is a shunt to *A*. By connecting *d* to faucet c_6 it would receive no current, because the pressure there is zero.

11. Hydraulic Analogy of a Series-Rheostat.—The series-principle made use of in Fig. 3 may here be further elucidated by a similar analogy that may help to emphasize the difference. Fig 5 illustrates the series-principle. It is similar

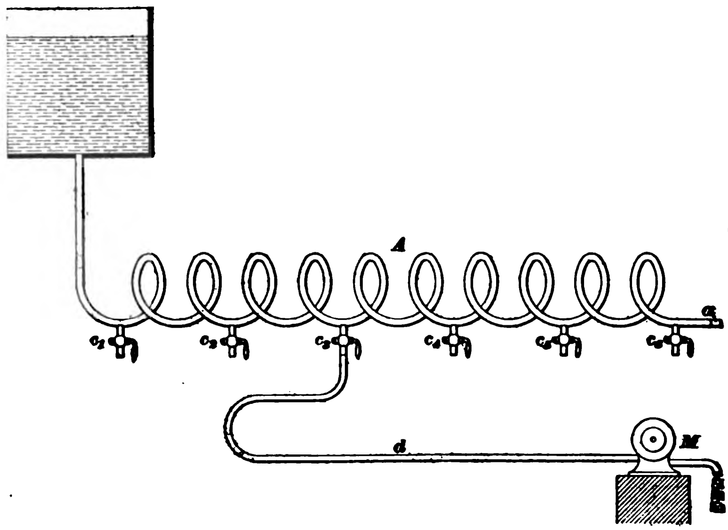


FIG. 5.

to Fig. 4 in all respects, except that one end of the coil is provided with a cap *a* which prevents any flow except through the faucets. If now, for instance, the hose *d* is connected to c_3, the water will flow through the coils up to that point, and beyond that the water will be at rest in the coil. It may therefore be said that this arrangement represents a series-combination, as all the water must flow through the coil before it can reach the motor *M*.

12. Comparison of the Two Methods.—At first glance there may appear to be little difference between these two arrangements, and that by the latter combination it would be possible to secure the same kind of variation in pressure as with the former, but this is not so. It must be remembered that in Fig. 4 the water is constantly flowing entirely unhampered through the coil and of nearly uniform strength, providing the resistance of the hose d is great, compared with that of A. This is not the case in Fig. 5. Here the current, after leaving the coil, is subjected to the high resistance of the hose d, and, consequently, is reduced in strength. The decrease in pressure will, therefore, not be 10 pounds at each faucet, but something less. Consequently, when connection is made with c_6 there is still a pressure sufficient to start a current and no zero position is obtainable. When no water is flowing through any of the faucets, the pressure is uniform at all of them.

13. Shunt Rheostat for Electric Circuits.—Let us now apply the combinations just explained to an electric circuit,

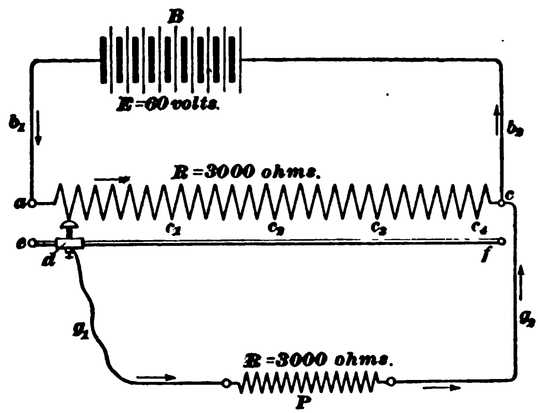


FIG. 6.

as illustrated in Fig. 6 in which B is battery that sends a current through the resistance-coil $a\,c$ by means of conductors $b_1\,b_2$; d is a contact-shoe that may slide along the rod $e\,f$ and make contact with the coil at any desired point. The patient P communicates with the shoe d by means of conductor g_1 and with the other end of the coil by the conductor g_2. A current will now flow constantly through the coil in the direction indicated by the arrows, and the current will suffer a certain loss while passing through said coil, the pressure at a being a maximum. It is clear that by sliding the shoe along from left to right any variation in pressure may be derived from maximum down to zero.

If the E. M. F. of the battery is 60 volts, the resistance of the coil 3,000 ohms, and the resistance of the battery is neglected, the current-strength through the coil will be $C = \frac{E}{R} = \frac{60}{3,000} = .02$ ampere. If we imagine the coil to be divided into 4 equal parts at c_1, c_2, c_3, c_4, then the pressure at a will be 60 volts and at c_1, c_2, c_3, c_4, 45, 30, 15, and 0 volts, respectively. In case the resistance of the patient is 3,000 ohms, the current-strength through the same will, when the contact-shoe occupies in succession the points indicated, be 20, 15, 10, 5, and 0 milliamperes, respectively. Of course any intermediate points will give corresponding intermediate values. That no pressure or current should be received at point c_4 may, at first, seem strange, because as long as a current of .02 ampere or 20 milliamperes is passing at this point, it would seem that part of this current at least, should pass through the patient. But it must be remembered that when the shoe d stands at c_4, there is no difference of potential between the conductors g_1, g_2; we have previously seen that this is the first requisite for starting a current through a circuit, in this instance that of the patient.

By means of this shunt combination, it is possible to provide a branch circuit, such as the human body, with any amount of electric pressure, depending on the resistance of the coil $a\,c$ and the current-strength through the same. By increasing both the resistance and the amperage, the drop of potential will be increased and likewise the available pressure in the shunt circuit.

14. Series-Rheostat.—We may now proceed to the electric analogy of the circuit shown in Fig. 5. This is represented in Fig. 7. B is a battery of 60 volts, $a\,c$ is the resistance-coil of 3,000 ohms, and P the patient with a resistance of 3,000 ohms. If the shoe occupies the position indicated, all the resistance of the coil is cut out and the maximum current is sent through P. It will be $C = \frac{E}{R} = \frac{60}{3,000} = .02$ ampere, or 20 milliamperes, if the resistance of the battery is left out of consideration. When the shoe d is placed next to the end c, all the resistance will be in series with the patient and a minimum current will flow, amounting to $\frac{60}{3,000 + 3,000} = .01$ ampere, or 10 milliamperes. This minimum current-strength can only be reduced by increasing the resistance of the coil $a\ c$.

15. Choice of Series or Shunt Rheostats.—Either of these methods, or both combined, is used for regulating current-

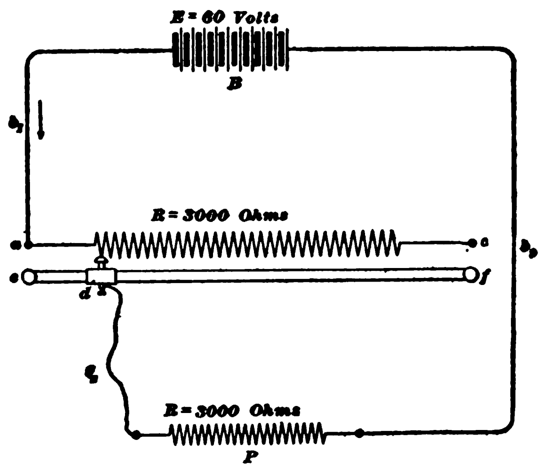


FIG. 7.

strengths in electrotherapeutics, and the apparatus described is called a *rheostat*. Sometimes the devices described in Figs. 6 and 7 are named volt-selectors, because they enable the operator to select the voltage to which he wishes to submit the patient. Whether to select the shunt or series-method depends somewhat on the conditions. When a voltaic battery is furnishing the current, many prefer the series-arrangement, because in this case there is rarely more current than is needed; and for economical reasons it is preferred not to let the current flow away uselessly in the main circuit, as it would through the coil *a c* in Fig. 6.

When the commercial lighting circuit is utilized, it is mainly a question of reducing a high pressure to a lower one, besides that of safety. It is not advisable to have the patient in series with the main circuit as he, in case of a short-circuit on the line, would be exposed to any high-pressure current that may accidentally be sent over the same.

Sometimes for the sake of finer regulation, an additional shunt is made to a shunt, but it will not be necessary to illustrate and explain this any further, as the student will be able to see the effect by a little study.

16. Rheostats in Their Commercial Forms.—The utilization of a contact-shoe, as shown in Figs. 6 and 7, indicates simply the principle applied in varying the pressure and not the actual construction, and some of the rheostats as used in practice will therefore now be illustrated and explained. It is clear that the main part of a rheostat is the resistance that is included in the same. How large this resistance must be or of what material it preferably is made, depends very much on the purpose for which it is intended. The resistance may either be a group of incandescent lamps, the carbon filament being the active part; a coil of high resistance wire, such as German silver; a column or ring of carbon or slate; or a combination of the latter materials.

The general principles of the wire rheostat was illustrated in Fig. 3. Ordinarily, the wire coils are embedded in some insulating materials and are invisible. At certain intervals they are connected with metal buttons that project through the rheostat surface and thus permit contact to be made with the revolving lever.

17. Carbon Rheostat.—Most rheostats are simply variations of the wire rheostat, in which the resistance-coil is replaced by a resisting path made either of carbon or mixtures of carbon with some other material. Fig. 8 is a rheostat, the upper surface of which is made of slate to which a carbon coating has been given by rubbing it with a fairly hard pencil. The carbon deposited in this manner serves as a path of a sufficiently high

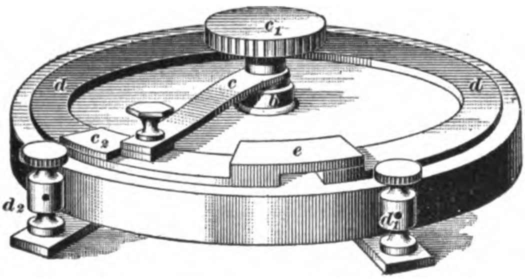


FIG. 8.

resistance. The length of this path is varied by placing a lever *c* with the copper spring c_2 at various distances from the stop *e*. This layer of graphite needs to be renewed at intervals by being rubbed over with a pencil; in the same manner the total resistance of the path can be decreased by depositing a thicker layer of graphite on the same. There are also other forms of carbon rheostats in which the carbon is permanently embedded in the insulating mass.

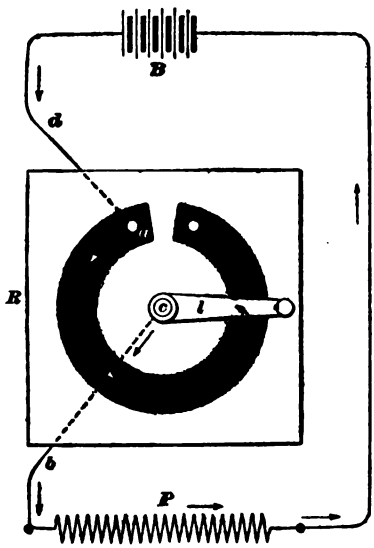


FIG. 9.

18. A Carbon Rheostat in Series and Shunt.—The patient's circuit may be connected with the rheostat either in series or shunt. To illustrate the difference between these connections, diagrammatic views of two such circuits are given in Figs. 9 and 10. In both of these the heavily shaded part represents the resistance path that the current follows through the rheostat. The series-arrangement is shown in Fig. 9. Here the current leaves the battery *B* through the conductor *d* and enters the rheostat through the binding-post *a*. It then passes along the rheostat, in the direction of the arrows, until it meets the lever *l*, through which it branches off into the post *c*, and from there through the conductor *b*, through the patient *P*, back to the battery. The length of the path in the rheostat over which the current is compelled to travel, determines the resistance and, thereby, the current-strength.

In the shunt arrangement illustrated in Fig. 10, the current again enters at *a*, but traverses the whole resisting path, as shown by the arrows, and leaves it again at *b*, whence it returns to the battery. We have here conditions similar to those illustrated in Fig. 6. The lever *l* here plays the same role as the shoe *d*, that is, it selects the voltage to which the patient's circuit is to be subjected. In the present instance, one-fourth of the available voltage is impressed on the patient's circuit, because the lever *l* occupies the first quarter of a complete revolution and in that position offers the current a by-path over which it will flow through conductor *d*, toward the patient *P*, and from thence return to the binding-post *b* and battery *B*.

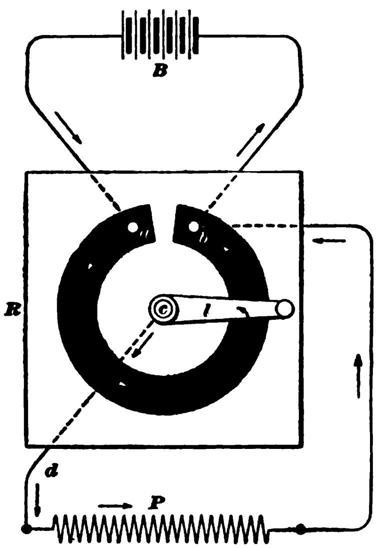


FIG. 10.

The difference between these two arrangements has been pointed out by means of Figs. 6 and 7 and requires no further mention at this point.

19. Another Carbon Rheostat.—Instead of having the carbon in the form of a circular plate, it may also be used in a cylindrical form, as shown in Fig. 11, where *a* is the carbon rod supported in the brackets b_1 and b_2. The rod *c*, besides serving as a shunt to the rod *a*, also guides the contact-spring *d* with which the current-strength is regulated. A current is sent by the battery *B* through conductor g_1 into binding-post *e*, and thence through bracket b_1, rod *a*, post b_2, to binding-post *f*, then through conductor g_2 back to the battery. At the same time, part of the current passes through the contact-shoe *d*, into rod *c*, post *i*, conductor h_2, and electrode E_2; from here it goes through the patient to the other electrode E_1, conductors h_1, g_2, and back to the battery. The rod *c* is insulated from the bracket b_1 by means of a hard-rubber sleeve, as indicated.

Arranged in this manner, the patient is in shunt with the rheostat and a current of maximum strength will, therefore, be supplied to him when the contact spring *d* occupies a position

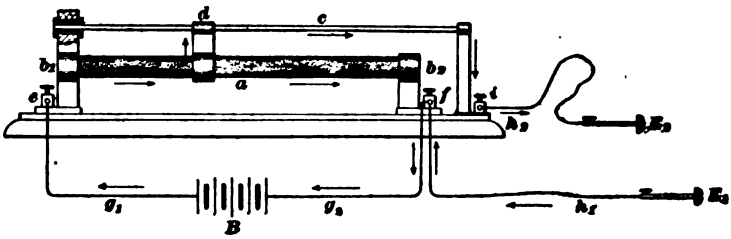


FIG. 11.

to the extreme left, and of minimum, or zero, strength when at the extreme right. It corresponds in its action very closely to the apparatus diagrammatically shown in Fig. 6.

20. Carbon Pressure Rheostat.—A rheostat based on a somewhat different principle, consists of a column of carbon powder, through the whole length of which the current is compelled to flow. Its resistance is varied by subjecting the column to more or less pressure; an increase of pressure brings the carbon particles in closer contact and decreases the resistance.

21. Bailey's Rheostat.—A combination of carbon and water is used in the rheostat shown in Fig. 12. *A* is a glass vessel, partly filled with water, *d*, *d* two triangular pieces of carbon supported by two rods *f*, *f*, which carry binding-posts

d_1, d_2 at one extremity and pinions c_1, c_2 at the other. Both of the latter engage with a worm provided with a milled head c. At the point of each carbon is a sponge s that constantly dips into the water, and thus makes the closing of the circuit more gradual. The conductors g_1, g_2 communicate with the carbons, and by turning the head c the carbons are made to dip more or less deeply into the water, thereby simultaneously increasing the sectional area and decreasing the length of the water-column situated between the two carbons.

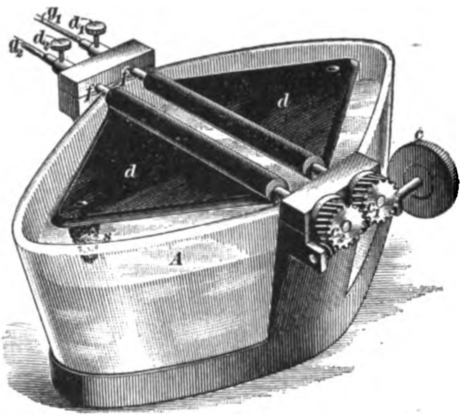


FIG. 12.

22. Fluid Rheostat.—Another **fluid rheostat** is illustrated in Fig. 13. A is a glass cylinder filled with a liquid of a certain specific resistance, depending on the voltage of the circuit. The cylinder is inserted in the base b and provided with a cap c. Through the base projects the rod d, which terminates in the ball d_1; at its other extremity it has a binding-post g_2. The current enters through the latter, and leaves the terminal d_1 to continue its passage through the liquid column until it meets the other terminal e_1, when it flows through the rod e into the cap c and out through the binding-

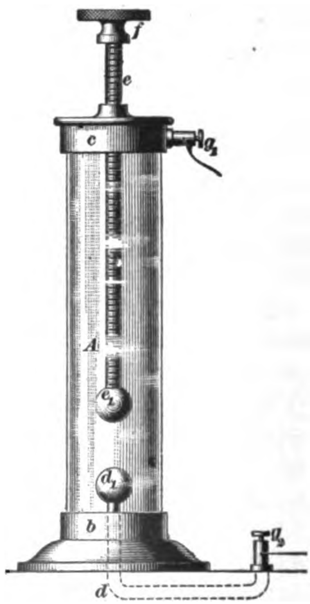


FIG. 13.

post g_1. The resistance is increased by turning the milled head *f* in a direction that will compel the threaded rod *e* to rise and thus increase the distance between the terminals d_1 and e_1. A rheostat of this form may be used in combination with an influence-machine, and control a current with more than 20,000 volts pressure.

23. Incandescent Lamps as a Rheostat.—When incandescent lamps are used as a rheostat they may be arranged as shown in Fig. 14 where *a* is the binding-post that connects them with the positive terminal of a commercial lighting circuit and *b* that with the negative terminal. It is supposed that a difference of potential of 110 volts exists between the two ter-

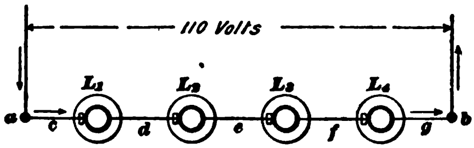


FIG. 14.

minals; and as there are four lamps in series, each lamp will consume one-fourth of the available voltage, or $\frac{110}{4} = 27.5$ volts. Therefore, while the current passes from connector *c* through lamp L_1 to *d*, it suffers a loss of 27.5 volts; from *c* to *e*, a loss of $2 \times 27.5 = 55$ volts; and from *c* to *f*, $3 \times 27.5 = 82.5$ volts. It is therefore possible, by suitable means, to select a voltage ranging from 27.5 to 110 volts. Of course, this combination could not be used directly as a rheostat for therapeutic purposes, because unable to give the finer gradations. It is customary to use it simply for effecting the main divisions of an available electric pressure and to let the smaller divisions be made by other means, such as a carbon rheostat. The lamps may then be arranged in the manner shown diagrammatically in Fig. 15. The lighting current enters through the binding-post *a* and passes successively through the four lamps L_1, L_2, L_3, L_4, and the other post *b* back into the main circuit. From the connections *d*, *e*, and *f* lead connectors to the contact-buttons

2, *3*, and *4*, with which the lever *l* may make contact. This lever will, therefore, act as a volt-selector, giving, in the position it now occupies, 27.5 volts, and 55 or 82.5 volts, respectively, when on the buttons *3* or *4*.

The carbon rheostat *R* is for the purpose of graduating the current-strength passing through the electrodes P_1, P_2 to the patient. The rheostat is connected in shunt to the lamps by letting the conductor *h* connect the binding-posts *a*, r_1, and the

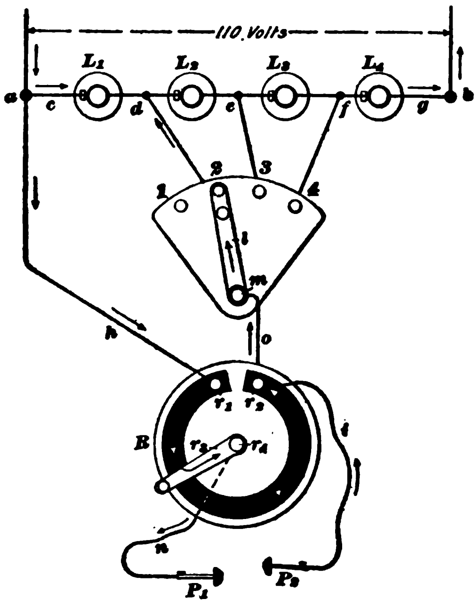


FIG. 15.

other conductor *o* the binding-post r_2 and *m*. From r_2 passes a conducting-cord *i* to the electrode P_2, and from r_4 another cord *n* to the other electrode P_1. The lever r_3 will adjust the current-strength through these electrodes. It is now seen that while a current is constantly flowing through the four lamps, a branch current is also continually passing through the conductor *h*, the rheostat *R*, conductor *o*, and lever *l*, through any of the conductors *d*, *e*, and *f*, depending on which button the lever may make contact with. In this manner the rheostat will be subjected to the voltage that any of these conductors may possess. When the lever connects with button *1*, the circuit through the rheostat is broken. The rheostat adjusts the current-strength from zero to the maximum that may be obtained from the various positions the lever *l* may occupy. If the lowest voltage of 27.5 volts is insufficient, the rheostat is brought into its zero position and the lever placed on the next button and this operation may be repeated until sufficient strength is obtained.

AMMETERS AND VOLTMETERS.

24. Principles of Ammeters.—If the electric current is to be used with any exactness, instruments are needed that will measure its strength and pressure. In its application to medical treatment this is particularly true, as the various purposes for which it is required demand various current-strengths. In some instances an overdose may not only be annoying but also dangerous, or may cause permanent injury.

When we speak of measuring the strength or pressure of an electric current, it must not be understood to mean that it is measured in the same manner as a gas meter measures the quantity of gas flowing through it, or as the pressure of the gas by means of a gage, giving the pounds pressure per square inch. The strength of an electric current is measured more nearly in the same manner as an anemometer measures the speed of the wind. The former does not count the cubic feet of air passing it per second, but is simply set in rotation by the air-current. By otherwise finding the relation between the number of revolutions per second, caused by a certain speed of this air-current the speed of the latter can be read directly from a scale.

So with electricity. We know that a coulomb per second constitutes an ampere, and it might therefore be supposed that measuring the number of coulombs would answer the purpose; but instruments of this character would not be practical for the present purpose. Neither would instruments based on the property of the current of depositing a certain amount of metal per coulomb of electricity.

In commercial measuring instruments, other properties of the electric current are found more convenient for use. Thus, modern instruments are based almost exclusively on the phenomena that two active conductors, or a magnet and a conductor, exert a certain mutual influence on each other; or, that an electric conductor will heat and expand in proportion to the number of amperes it transmits, and be able by means of the resulting elongation to operate a suitably arranged indicator.

25. The D'Arsonval Galvanometer.—Small currents were formerly mostly measured by means of the **galvanometer**; but lately such accurate and reliable portable measuring instruments have been made that these measurements may be carried out with as great a degree of precision and with much greater facility. Therefore no description will be given of any galvanometer except the **D'Arsonval Galvanometer,** on the principles of which some of the best modern measuring instruments have been based. This instrument is illustrated by means of Fig. 16, and consists mainly of a large permanent magnet *PP*, between the poles of which

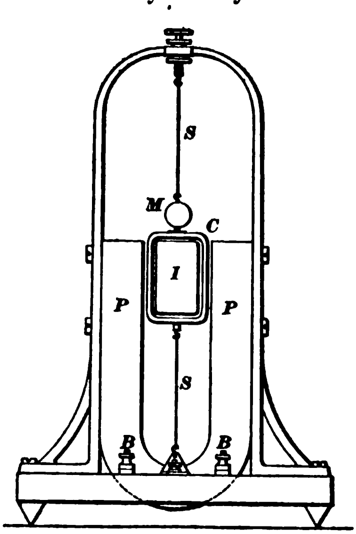


FIG. 16.

is suspended a coil of wire *C*. The current is led to the coil by means of the platinum wires *S*, *S*, which suspend the coil, and it will cause the coil to turn in the same manner as a magnetic needle, and for the same reasons. The magnetic lines of force produced in the coil tend to place themselves, and therefore the coil, in a position where they will be parallel with those of the magnet, and run in the same direction. The coil would therefore adjust itself at right angles to its present position, if this tendency were not opposed by the suspension, which may be a spring or an elastic wire. A pointer may be attached to the coil to indicate its deflection, though usually a mirror *M* is used, a reflected beam of light from which forms the pointer, as will be shown by means of Fig. 17. In many forms of this instrument, a soft-iron core *I* is supported between the poles of the magnet, a space being left between the core and the magnet in which the coil swings. This core serves to reduce the reluctance of the air-space, and the strength of the field will therefore be increased in proportion.

By suitably shaping the poles of the magnet, the intensity of the magnetic field, in various parts, may be so varied that the

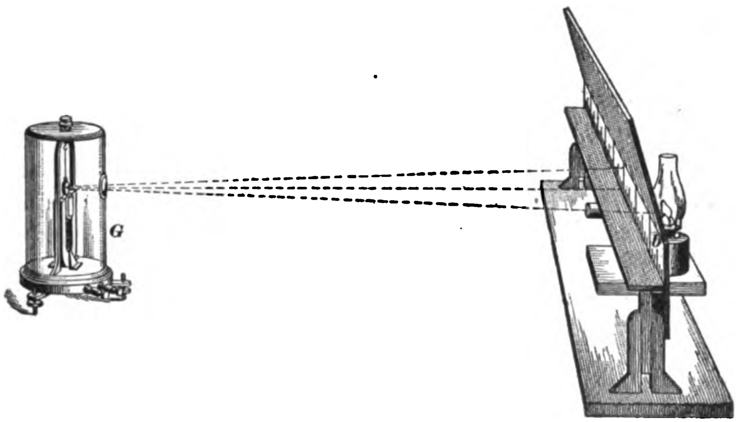


FIG. 17.

movement of the beam of light will be directly proportional to the current in the coil.

Connection from the binding-posts *B*, *B* to the coil *C* is made through the platinum wires *S*, *S*. One of the chief advantages of this instrument is the fact that external fields, such as the earth's magnetism, have little effect upon it, so that it requires no controlling magnet or correction for the earth's field, and it may be used near dynamos or large masses of iron without being affected. In Fig. 17, the galvanometer *G* is shown in combination with a lamp and scale, on which a reflected image of the lamp flame will move back and forth. Under the scale *b* is a little lens tube, with a short piece of wire placed vertically across the tube. The light from the lamp is, by means of the galvanometer mirror, reflected on the scale *b*, where the cross-wire will show itself as a dark line on a light spot. If the mirror moves through an angle of 1°, the light beam will move through an angle of 2°, and the galvanometer will therefore be able to indicate most minute currents. In some galvanometers, it is thus possible to indicate the pressure of 1 microampere by the motion of the light through a distance of about .04 inch.

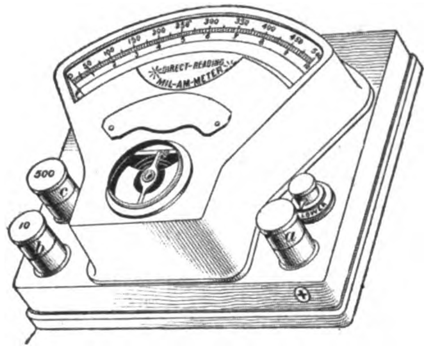


FIG. 18.

26. The Weston Milliammeter.—The **Weston milliammeter,** shown in Fig. 18, is made on the same principle as the D'Arsonval

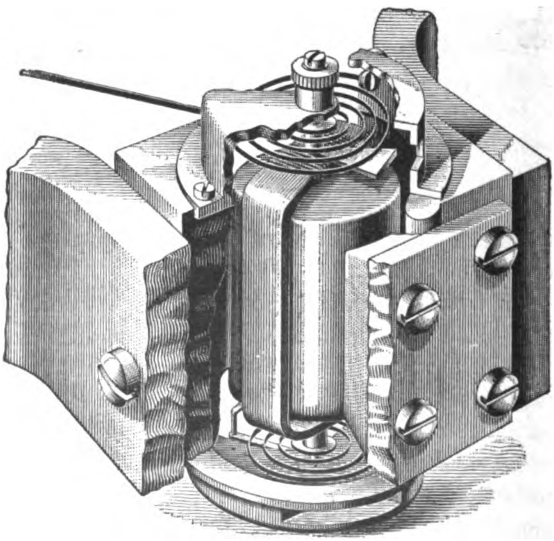


FIG. 19.

galvanometer, and is among the best known forms of portable instruments. Fig. 19 gives a detailed view of the coil and pole-pieces, partly broken away, and Fig. 20 a separate view of the magnet and stationary core. The permanent magnet *A A* has soft-iron pole-pieces *P*, *P* fastened to it by the screws *S*, *S*, and bored out to make a cylindrical opening. In the center of this opening is a stationary soft-iron cylinder *C*, supported in place by a screw *M* passing through a lug on the brass plate *B*. The cylinder being of a smaller diameter than the opening through the pole-pieces, there is left a narrow gap between the pole-pieces and the iron core, as shown. The lines of force from the permanent magnet pass across this space, making a strong and uniform magnetic field.

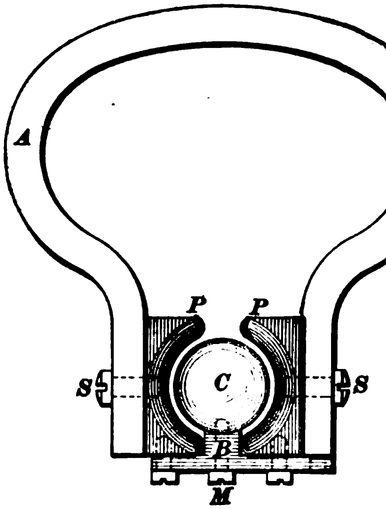


FIG. 20.

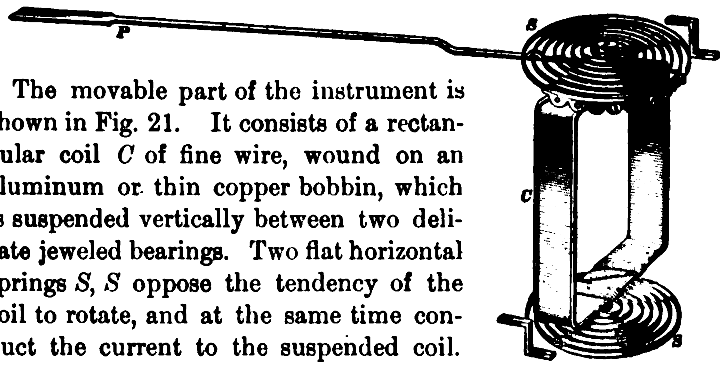


FIG. 21.

The movable part of the instrument is shown in Fig. 21. It consists of a rectangular coil *C* of fine wire, wound on an aluminum or thin copper bobbin, which is suspended vertically between two delicate jeweled bearings. Two flat horizontal springs *S*, *S* oppose the tendency of the coil to rotate, and at the same time conduct the current to the suspended coil. A thin aluminum pointer *P*, attached at right angles to the coil, moves over the scale and indicates the deflection of the coil from its normal position, which is as shown in Fig. 18. When a current is sent through the coil, the latter moves until the torsion of the springs equals the force with which the coil tends to move, when the coil comes to rest and the pointer indicates the angle of deflection of the coil.

The copper or aluminum bobbin on which the coil is wound, in moving through the magnetic field, has an electromotive force set up in it, which causes a so-called Foucault current, mentioned in *Magnetism and Electromagnetism*, to circulate around the bobbin, so long as the latter is in motion. This current circulates in an opposite direction to that in the coil; hence, it tends to oppose the motion of the coil, and has the effect of preventing the needle from swinging too far over the scale, thus bringing it quickly to rest at the proper point. When an instrument possesses this quality it is known as a *dead-beat* instrument. It is a very important feature, and one that materially increases the rapidity of taking measurements.

FIG. 22.

The instrument has two scales. For currents up to 10 milliamperes the lower scale is to be used; terminals *a*, *b* will then be connected. For currents up to 500 milliamperes, the upper scale is to be used; in this case terminals *a*, *c* will be connected.

27. Other instruments are based mostly on the action of a stationary coil on a movable magnet needle. Fig. 22 shows an instrument of this class in which the needle is vertical.

For the measurements of pressure or voltage, instruments very similar to those already described are used. The moving system is practically the same for all direct-current Weston ammeters and voltmeters.

SIMILARITY OF AMMETERS AND VOLTMETERS.

28. Analogy From Hydraulics.—The similarity existing between *ammeters* and *voltmeters*, and the possibility of substituting one for the other, is a circumstance that is very difficult for beginners to understand. That an instrument which serves to indicate current-strength in one position can indicate current-pressure in another, seems to be an incongruity. It is not that there is any intrinsic difference between the two instruments; it is rather their different positions relative to the circuit to be tested that makes it possible for them to indicate amperes in one position and volts in another. An analogy from hydraulics will perhaps help to clear this matter up.

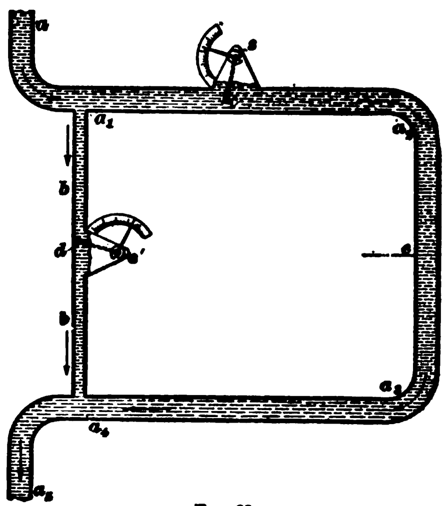


FIG. 23.

Let $a\ a_1\ a_2\ a_3$, etc., Fig. 23, be a pipe of large diameter, through which a certain volume of water is constantly flowing. If a small paddle, or vane, *c* be suspended somewhere in the tube, in the path of the current, and forced to a zero position by means of a spiral spring *s*, the deflection of the vane will depend on the current-strength, and can be indicated by means of a pointer on a scale. By measuring the number of gallons passing the vane *c*, by use of a water meter, the former may easily be made to register the flow in gallons per second, and its function would correspond to that of an **ammeter** when measuring the strength of an electric current.

29. We will now see how the same vane may be utilized for indicating the pressure with which the water is propelled through the part of the tube marked $a_1\ a_2\ a_3\ a_4$. Evidently this pressure is similar to the E. M. F. of an electric circuit. The pressure at a_4 must be lower than at a_1, and the difference between these two pressures is the pressure required to force the water through the part of the circuit included between these two points. If we establish a current between the points a_1 and a_4 by means of a tube *b*, water will flow through the latter, for obvious reasons. Such a connection will correspond to what, in electric circuits, is called a **short circuit.** In other words, the water will have an opportunity of going either partly or wholly through the tube *b*, and will therefore affect the indications of the vane *c*.

To obviate this, the tube *b* is made so small in diameter that the current passing through it is insignificant in comparison with the main current, but large enough to operate the vane *d* placed in its path. The vane *d* will now move in the same manner as *c*, and for the same reasons; but there is this difference: while the latter vane is operated by the whole current, the former is affected only by part of it. The greater the difference in pressure between the points a_1 and a_4, the more water will flow through the tube *b* and the farther will the vane *d* be deflected. The relation between these deflections and the excess of pressure at a_1 over that at a_4 may be determined, and we then have in the vane *d* an instrument similar to a **voltmeter.** If the flow of water past the vane *c* were stopped by closing a valve situated at *e*, the vane *d* would still be able to register the difference in pressure between the points a_1 and a_4, as a current would continue to flow through the tube *b* and thus deflect the vane *d*.

30. It would seem reasonable to think that, if this vane *d* can indicate the difference of pressure between a_1 and a_4, it should also be able to indicate, by means of a separate scale, the current-strength around the circuit a_1 a_2 a_3 and a_4, because the latter is proportional to this difference of pressure. But it must be remembered that the required surplus pressure at a_1 will not only depend on the strength of the current, but also on the resistance of this part of the circuit. In fact, the tube may either be very long, with a small current, or short with a heavy current; the instrument at *d* will make no distinction between these two combinations. If the resistance of this circuit were constant, then the vane *d* might also indicate the current-strength, as the latter would be directly proportional to the pressure.

31. Ammeter and Voltmeter in an Electric Circuit. It will now be easier to understand the relation between a voltmeter and an ammeter in an electric circuit, and how one may replace the other. In Fig. 24 we have an electric circuit very similar in its general arrangement to the hydraulic circuit of Fig. 23. *B* is a voltaic battery sending a current through the

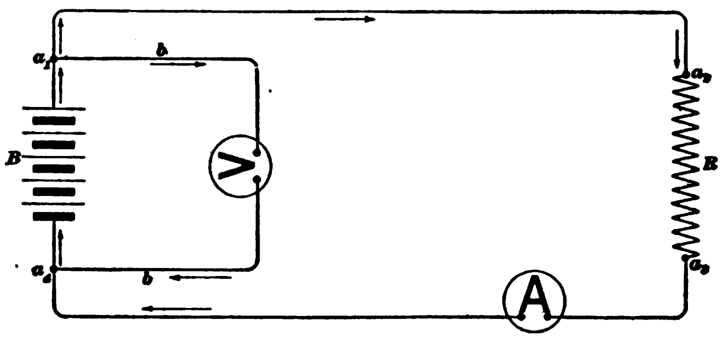


FIG. 24.

conductor a_1 a_2, through an external resistance *R*, and then through the conductor a_3 a_4 back to the battery. In the main circuit is inserted a milliammeter *A* in series, while, in the branch circuit *b b*, a voltmeter *V* is placed in parallel with the battery. Nearly the whole current is therefore passing through the milliammeter, and its strength is there indicated in milliamperes; only a small portion of the current passes through the voltmeter, and there its pressure is indicated in volts.

32. By virtue of their position in the circuit, it is clear that in one respect they must differ widely from each other. Take, for instance, the milliammeter, which is so situated that it receives most of the current. Evidently, it would materially lower the efficiency of the whole circuit if this instrument were in possession of a high resistance, with the resultant loss of voltage. The resistance must therefore be made as low as possible; in fact, so low that if the instrument is in circuit for days there would be no perceptible heating of its coils. This we also find to be the case with efficient meters; thus, for instance, a 15-ampere Weston ammeter has an internal resistance of .0022 ohm. When measuring a 10-ampere current, the drop ($C \times R$) is .022 volt, and the watts expended ($C \times E$) = .22, or about $\frac{1}{3400}$ horsepower.

33. With the voltmeter, the requirements are exactly the opposite; the resistance must be as high as possible, consistent with an efficient action of the instrument. If the resistance of the voltmeter were as low as that of the milliammeter, the greater part of the current would pass around the battery through the conductors *b*, *b* and would thus act as a short circuit. The resistance of a Weston voltmeter is about 19,000 ohms. Measuring 110 volts, the instrument would take $\frac{110}{19000} = .0058$ ampere, nearly, with a consumption of energy of .638 watt, nearly, or about $\frac{1}{1200}$ horsepower.

34. It may be suggested that the voltmeter in the position indicated in Fig. 24 should also be able to act as an ammeter by using an additional scale, it being claimed that the current is proportional to the pressure in volts. But it must be remembered that while the current-strength depends on the pressure it also depends on the resistance. For instance, let the resistance R, Fig. 24, be 50 ohms and the current-strength 500 milliamperes; then the required voltage would be $C \times R = .500 \times 50 = 25$ volts. The voltmeter would indicate this pressure, but we see at once that this E. M. F. would also be sufficient to send a current of 2 amperes through a resistance of 12.5 ohms; in fact, these two factors may vary between wide limits, so long as their product remains 25 volts. It is seen, therefore, that, for a voltmeter to indicate amperes, it must be in circuit with a constant or known resistance. This principle is made use of in the Weston ammeter, which makes it unnecessary to let the whole current go through the movable coil. The latter is connected in parallel with a short, thick piece of copper or some alloy (see a, Fig. 25) so that only a small part of the current passes through the coil, and the resistance of the instrument is extremely low. The ammeter is then more in the position of a voltmeter in parallel with a circuit of constant resistance, and now in reality measures the loss of voltage in the piece of copper a, where a_3 and a_4 are the two ends of the circuit, C the moveable coil, and S, S the conductors connecting the coil in parallel with the main circuit. The loss of potential in a will now be in direct proportion to the strength of the current through the strip a; and, as this loss determines the difference in potential between a_3 and a_4 on which the current through C depends, it is clearly seen that this current is directly proportional to the main current. Thus, while the coil C might operate as a voltmeter for the local conductor a, it will also serve as an ammeter for the whole circuit of Fig. 24, if properly calibrated.

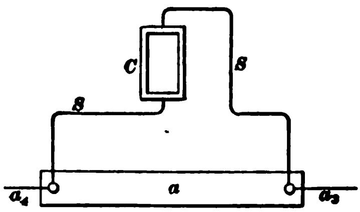


FIG. 25.

35. We then come to the conclusion that ammeters and voltmeters are in reality both ammeters; that is, they are instruments actuated by an electric current passing through a movable coil placed near a stationary magnet, or through a stationary coil acting on a movable magnetic needle. In the ammeter proper, the strength of this current depends on the E. M. F. and the resistance of the whole circuit of which the ammeter forms a part; it may also depend on a certain fixed portion of the total current for its operation, when the ammeter constitutes part of a parallel circuit.

36. In the voltmeter, the strength of the actuating current depends on the difference of potential between the points to which it is attached and the resistance of the local circuit formed by the voltmeter and its connections. We see, then, that the voltmeter is similar to an ammeter when this is provided with a local resistance, as shown in Fig. 25.

37. An Ammeter Changed Into a Voltmeter.—An ammeter of this class should therefore be capable of being transformed into a voltmeter by adding enough resistance to retain the original calibration, but reading volts instead of amperes. An example will illustrate this.

A milliammeter has a resistance of 20 ohms. If the meter is to serve as a voltmeter and the divisions in milliampers are to be read as volts, what external resistance must be added?

It is supposed that the ammeter at present measures up to 1 ampere. The resistance being 20 ohms, it requires an E. M. F. of $C \times R = 1 \times 20 = 20$ volts to bring the pointer to indicate 1,000 milliamperes. To be capable of registering 1,000 volts, the resistance must be increased to 1,000 ohms, as then, according to formula $E = C \times R$, 1,000 volts = 1 ampere × 1,000 ohms. The required addition to the present resistance is therefore 1,000 — 20 = 980 ohms.

If the instrument shall read to 100 volts only, then, placing $E = 100$ volts, we have $R = \frac{E}{C} = \frac{100}{1} = 100$ ohms, and the needed addition will be 100 — 20 = 80 ohms. In this instance every 10 divisions of milliamperes will represent 1 volt.

38. Difference Between Ammeters and Voltmeters. Before leaving the subject of ammeters and voltmeters, there is yet one point to mention, which is not always understood. Why is it, for instance, that an ammeter can be short-circuited with impunity, but cannot be removed from the circuit, while a voltmeter must not under any circumstances be short-circuited, but may be disconnected? Let the diagram in Fig. 26 show a voltaic battery combined with an electric bath. The resistance of the circuit is 90 ohms, the E. M. F. 30 volts, and therefore the current $C = \frac{E}{R} = \frac{30}{90} = .333$ ampere. B is the voltaic battery, a_1 the conductor sending the current to the bath C, and a_2 the return circuit. The milliammeter A is placed in series with the conductor a_1, and the voltmeter V in parallel with the bath by means of the conductor $b\,b$. It is now seen that the whole current passes through the milliammeter A before it reaches the bath, and that by disconnecting this instrument the circuit will be broken and the current stop its flow. If, on the other hand, the milliammeter be short-circuited by means of the additional conductor a, it will have no influence on the circuit as a whole, the resistance of the instrument already being so low as to be left out of consideration, but will rather have the effect of removing the instrument from the circuit.

39. With the voltmeter, we find the opposite to be the case. Here a removal of the voltmeter would leave the rest of the circuit unaltered, and the current would continue to flow through the bath; but let the voltmeter be short-circuited by means of the conductor b_1, then the conductor b would no

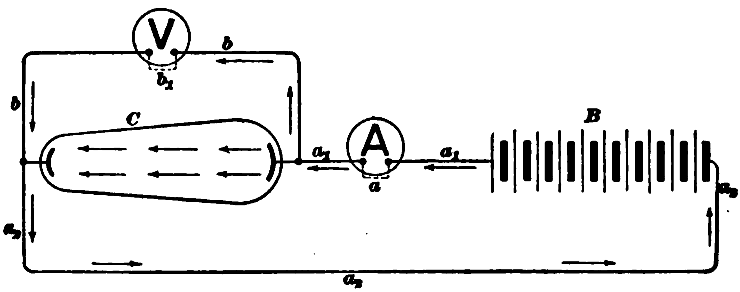


FIG. 26.

longer be limited in its conductivity by means of the high resistance of the voltmeter, and would tend to carry the whole current of the battery. It would, therefore, short-circuit the bath and consequently also the battery, and would very likely injure the latter; otherwise, the damage might be little. When it comes to circuits with higher voltage and amperage; as, for instance, in a lighting circuit, the consequences would be more serious.

In Fig. 27 we have, for instance, the conductors a_1 and a_2 leading to a combination of incandescent lamps L in a house. The lamps are all placed in parallel and the ammeter A inserted in the conductor a_1, while the voltmeter V, by means of wires b, b is connected with both conductors, and therefore is in parallel with the lamps. If, now, the ammeter be again short-circuited by the wire a_2, it will have no effect on the circuit, but will simply throw the ammeter out of action; whereas removing the ammeter altogether, before being short-circuited, would, of course, break the circuit and extinguish all the lamps.

A short-circuit of the voltmeter by means of the wire b_1 would not only affect the lamps in this house but in the whole neighborhood. It would send a very strong current across the conductors b, b_1, b, and either melt these wires or the safety-fuse which may be situated there. A fuse consists of a strip of metal through which an ordinary current will pass unimpeded,

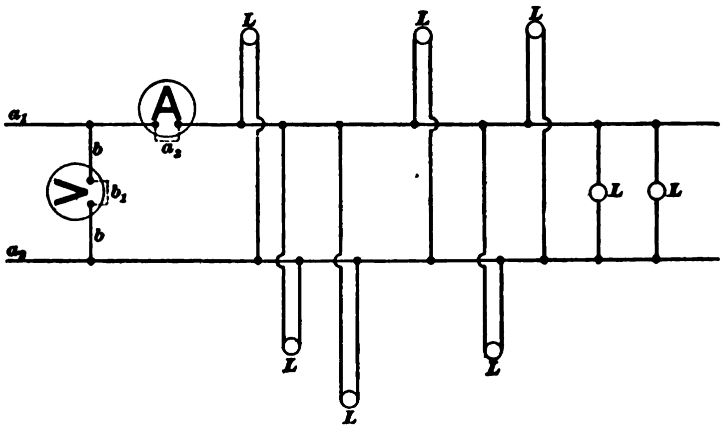


Fig. 27.

but which will heat and melt if the strength of the current goes beyond certain determined limits; it will, therefore, break the circuit and prevent any serious damage to the rest of the apparatus. Disconnecting one of the wires leading to the voltmeter, while in circuit, will have no other effect than simply removing the instrument from the circuit.

INFLUENCE OF RESISTANCE ON E. M. F. AND CURRENT.

40. After the functions of the voltmeter, ammeter, and rheostat have been studied separately, it remains to be seen how these instruments work in conjunction with one another. The effect that the rheostat has on the various parts of a circuit is a subject that is not clearly understood by beginners, and therefore requires some explanation, particularly as the rheostat plays such an important part in electrotherapeutics. The question to be answered is: Does the rheostat affect the current-strength only, or does it also affect the pressure at the battery terminals?

If this question were to be answered off-hand, it would seem, as a matter of course, that any resistance the rheostat might insert in the circuit would merely increase the total resistance of the latter, and therefore diminish the current-strength. A closer study of the condition will show that this answer is not quite correct, but that an increase of the resistance does in fact increase the available E. M. F. at the battery terminals. Of course, this does not mean that it increases the total E. M. F. generated by the battery; on the contrary, this E. M. F. remains practically constant, so long as we deal with voltaic batteries and not with dynamos or other generators.

41. Some practical examples, illustrated by means of Figs. 28, 29, 30, 31, and 32 will make the reasons for this perfectly clear.

Let the battery *B*, Fig. 28, consist of 10 cells, each of an E. M. F. of 1.2 volts and an internal resistance of .5 ohm. The

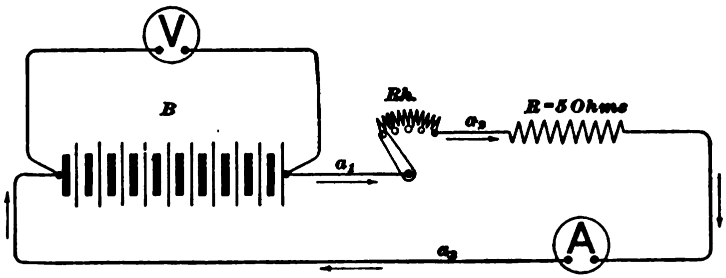


FIG. 28.

total E. M. F. of all the cells in series will therefore be $10 \times 1.2 = 12$ volts, and the total internal resistance $10 \times .5 = 5$ ohms.

In the same figure, *R* is an external resistance of 5 ohms, and *Rh.* a rheostat, which, by means of the conductors a_1 and a_2, connects, respectively, with the battery and the resistance *R*;

the conductor a_3 returns the current from the latter to the battery. A voltmeter and a milliammeter complete the arrangement.

It is the purpose, by means of this combination, to send a current from the battery *B* through the external resistance *R*, which latter may, for instance, be the resistance existing in a cautery loop applied to the human body for some local treatment. The number of amperes that will flow through this external resistance is to be controlled by means of the rheostat.

42. When no resistance is inserted by the rheostat, and the only resistances in circuit are those of the battery and the cautery, the conditions will be those represented in Fig. 29. Here we find the whole circuit of Fig. 28 extended along a horizontal line *a h*, representing zero potential, and the parts marked off in the same order as in the former figure. It is supposed that the point *h* connects directly with the point *a*, and that the various

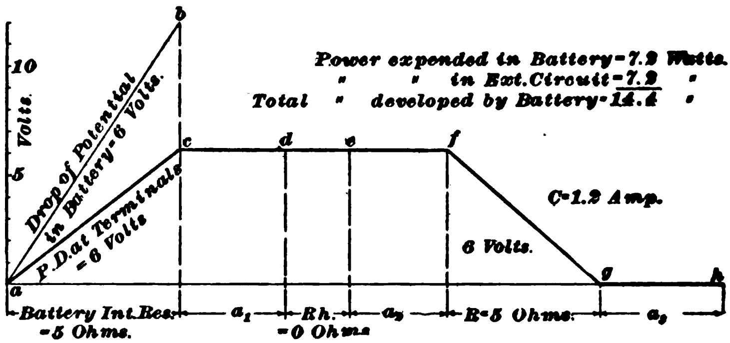


FIG. 29.

divisions marked with the letters a_1, *Rh.*, a_2, etc. correspond to the parts marked with similar letters in Fig. 28. It is also supposed that the conductors a_1, a_2, and a_3 are of such ample cross-sectional areas that the drop of potential taking place in them may be left out of consideration.

Beginning, then, with Fig. 29, we find, as the only resistances in circuit are the 5 ohms of the battery and the 5 ohms external resistance, that the strength of the current will be

$C = \frac{E}{R} = \frac{12}{5 + 5} = 1.2$ amperes. At the left end of the figure the line $a\,b$ indicates a rise of potential of 12 volts, which would take place if the battery were devoid of internal resistance. But a current of 1.2 amperes having to pass through its resistance of 5 ohms, the current suffers a loss in potential of $C \times R = 5 \times 1.2 = 6$ volts. The potential difference at the terminals of the battery will therefore be $12 - 6 = 6$ volts only, as represented by the line $a\,c$, and this is the pressure that will have to carry the current through the rest of the circuit. No resistance being inserted by the rheostat, and the resistances of the conductors a_1 and a_2 being left out of consideration, the potential of the current will remain unaltered while passing through them, and the lines $c\,d$, $d\,e$, and $e\,f$, representing the potential of these parts, will be lines parallel with the zero-line $a\,h$. At f the current enters the external resistance R of 5 ohms, and here suffers a loss of pressure amounting to $C \times R = 1.2 \times 5 = 6$ volts. This means that the whole available pressure of the battery has been consumed in the resistance R, and that the current now, through the conductor a_2, again enters the battery at zero potential.

43. It was shown in *Direct Currents* that a battery gives a maximum power to an external circuit, when the resistance of said circuit is the same as that of the battery. As this corresponds with the conditions found in Fig. 29, we shall expect to here find a maximum power spent in the resistance R. The power expended on the various parts of the circuit is found by multiplying the loss of potential that the current suffers in passing through them by the strength of the current in amperes. The total power developed by the battery is $E \times C = 12 \times 1.2 = 14.4$ watts. That part of the total power which is spent in the battery itself, we find by multiplying the drop of potential in it by the current, or $6 \times 1.2 = 7.2$ watts. The external resistance R being equal to that of the battery, the drop will be the same, and therefore, also, the power consumed. We see, then, that, of the total power of 14.4 watts, 7.2 watts have been spent, respectively, in the battery and in the external circuit.

If the battery had been short-circuited, the total power developed would have been greater, but of course none of it would have been available outside of the battery. The current C that would circulate through the latter, in this instance, would have a strength of $\frac{E}{R} = \frac{12}{5} = 2.4$ amperes, and therefore a power of $E \times C = 12 \times 2.4 = 28.8$ watts.

44. In Fig. 30 the conditions are altered, for, by means of the rheostat, a resistance of 5 ohms has been inserted, making

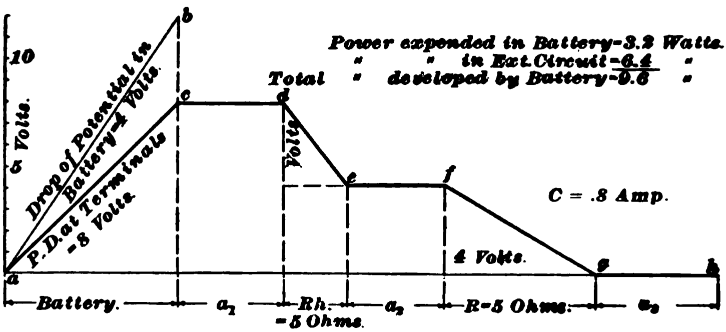


FIG. 30.

a total of $5 + 5 + 5 = 15$ ohms. The current-strength will now be $\frac{E}{R} = \frac{12}{15} = .8$ ampere, which is 33 per cent. less than that of the circuit shown in Fig. 29.

The strength of the current having decreased, it follows as a consequence that the loss of potential in the various parts of the circuit must also decrease, as these losses are products of current and resistance.

When we now calculate the loss of potential in the battery, it is found to be $C \times R = .8 \times 5 = 4$ volts, or 2 volts less than in Fig. 29; consequently the available E. M. F. at the terminals of the battery, or $12 - 4 = 8$ volts, must be larger than that previously at our disposal. Following the distribution of these 8 volts over the remainder of the circuit, we find, as before, that the current, while flowing through the conductor cd, suffers no loss of potential, but that, on passing through the 5 ohms resistance of the rheostat, the pressure at once falls from 8 to 4 volts, which pressure remains throughout the conductor ef; after leaving the latter the current again suffers a loss of 4 volts, caused by the 5 ohms resistance of the external resistance R.

Comparing the two examples, illustrated by means of Figs. 29 and 30, it is seen that the insertion of the rheostat resistance of 5 ohms has the effect of raising the available E. M. F. at the battery terminals from 6 to 8 volts, but that notwithstanding this increase the current-strength decreased from 1.2 amperes to .8 ampere. If the resistance and E. M. F. had increased in the same proportion, the current-strength would have remained the same; in this instance the exterior

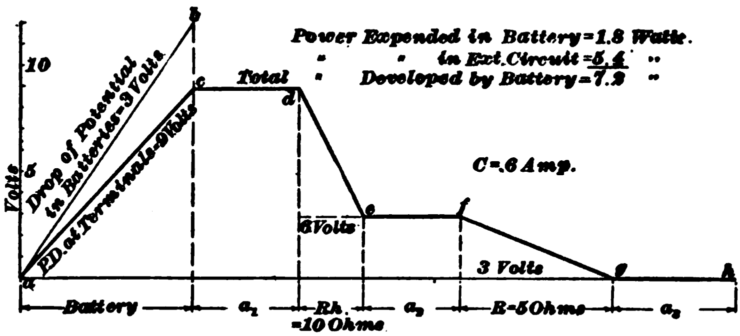


Fig 31.

resistance is increased by 100 per cent. and the terminal E. M. F. by 33 per cent. only; the latter, therefore, did not keep step with the former, with the result that the current decreased. Had the terminal E. M. F. remained the same as before, the current would have been .6 ampere only; but, being increased by 33 per cent., the amperage rose from .6 to .8 ampere.

We come, then, to the conclusion that increasing the resistance in the external circuit of a battery does not decrease the current in the same proportion, because the available E. M. F. increases simultaneously, though not in the same ratio.

45. In Fig. 31, the resistance of the rheostat is increased to 10 ohms and the current has now decreased to $\frac{E}{R} = \frac{12}{20} = .6$

ampere, while the drop of potential in the battery is 3 volts only, and therefore the available E. M. F. = 12 — 3 = 9 volts. The other losses in the circuit can easily be seen by the data given in the figure.

46. As a final example of the influence exerted by the rheostat, we will consider the circuit illustrated by means of Fig. 32. Here the rheostat has increased its resistance to 30 ohms, making a total resistance for the whole circuit of 40 ohms. The current has now fallen to $\frac{E}{R} = \frac{12}{40} = .3$ ampere. At the same time the loss of potential suffered in the battery has decreased to 1.5 volts, which leaves an available

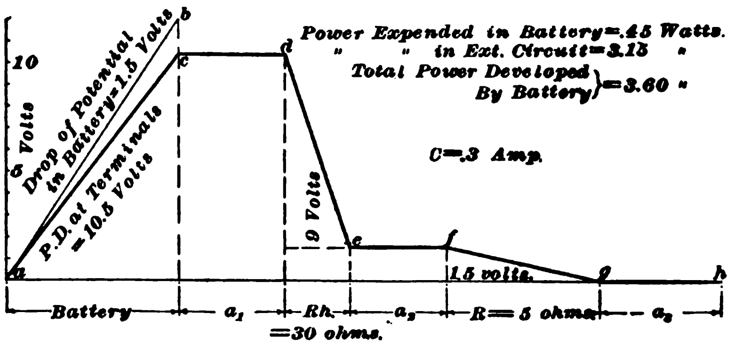


FIG. 32.

pressure at the terminals of 12 — 1.5 = 10.5 volts. In the rheostat the loss is now 9 volts, while in the permanent resistance R it is 1.5 volts only. This last example brings out more clearly another feature, that an increase of the resistance in the circuit external to the battery will bring the available pressure at the terminals nearer the total E. M. F. of the battery, and at the same time the current will decrease in strength. Finally, the resistance will be so great that the current practically stops altogether; the circuit is then in the same condition as when open, and the pressure at the battery terminals will be identical with the total E. M. F.

47. Data relating to the power spent in the external circuit are given in each figure. It is at once seen that the power has reached its maximum value when the conditions are as shown by Fig. 29; that is, when the external resistance is equal to that of the battery. An increase or decrease of the resistance in the external circuit will have the same result—that of decreasing the available power. Simultaneously with the decrease of the current the number of watts spent outside of the battery will also decrease until, in Fig. 32, the power spent has the value of 3.15 watts only.

48. The condition that must prevail if maximum power is to be given an external circuit may also be expressed in another way, by saying that, if a voltmeter, connected with a battery as in Fig. 28, indicates a pressure of one-half of the total E. M. F. of the battery, maximum work is being done in the external circuit. This of course does not mean that the resistance, outside of the battery, may be increased by means of a rheostat until the desired value of the terminal pressure is reached. It is true that in this case also maximum power is given to the circuit, but the resistance R receives only a small fraction of it, the greater part being uselessly wasted in the rheostat, where the electrical energy is changed into mechanical energy in the form of heat. It is therefore clear that, if a device external to the battery is to receive a maximum power from the battery, this device itself must constitute the external resistance.

CURRENT-SELECTORS AND POLE-CHANGERS.

49. Advantages of Current-Selectors and Pole-Changers.—There remains to mention a little device that is very useful to the physician when applying the electric current, and that is the double switch shown in Figs. 33 and 34. In construction it is identically the same in both illustrations, but its connections with the circuit are different and the results obtained are, therefore, also different. When the operator uses an apparatus called a *switchboard*, which is described further on, he has often the choice of two different kinds of current, such as the galvanic and the faradic. It is then of advantage to have the switchboard so arranged that either of these current varieties can be sent through the main binding-posts without having to make any change in the connections. This is accomplished by means of the **current-selector.** At other times it may be of advantage to change the polarity of the electrodes without having to disconnect them. Arranged for this purpose, the double switch performs the function of a **pole-changer.** Ordinarily these are used in combination, so that it is possible not alone to choose the current variety with which the electrodes are to be supplied, but also to change their polarity.

50. Current-Selectors.—A device of this kind is represented by the diagram Fig. 33. *B* is a voltaic battery that,

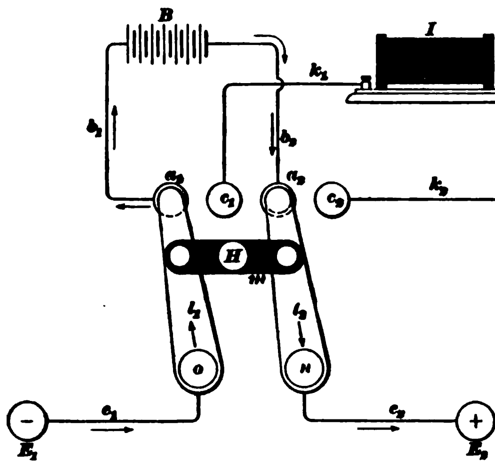


FIG. 33.

through the two conductors b_1, b_2, is connected to the buttons a_1, a_2. *I* is a faradic coil that connects with the buttons c_1, c_2 by means of conductors k_1, k_2. The levers l_1, l_2, compelled to move in unison by the cross-piece *m* (which is made of insulating material), may connect either with a_1, a_2 or c_1 c_2, respectively. They swing around the posts *n* and *o* and may be moved by means of the handle *H*. The main binding-posts E_1, E_2 connect with the levers through the conductors e_1, e_2. In the position that the levers at present occupy, a current is sent from the battery *B* to the posts E_1, E_2, and the faradic coil *I* is cut out. On moving the levers into a position so as to connect with buttons c_1, c_2, the faradic coil is included and the battery B excluded from the circuit and a faradic current will pass through the same posts E_1, E_2.

51. Pole-Changers.—When the double switch is used as a pole-changer, its connections are those shown in Fig. 34. Here the positive wire b_1 of the battery B is connected both to buttons a_1, d_2, thus making both positive. Similarly, the negative conductor c_1 is connected with buttons d_1, a_2, making both

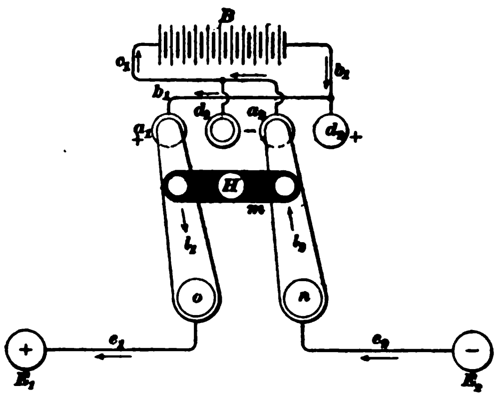


FIG. 34.

negative. Otherwise the connections are the same as in Fig. 33. When making contact with the buttons a_1, a_2 as shown, electrode E_1 will be positive and E_2 negative. On pushing the levers to the right, the polarity of the electrodes will be reversed and E_1 will now be negative and E_2 positive.

SWITCHBOARDS.

52. Function of Switchboards.—Under the term **Switchboards** is ordinarily understood a board having a collection of switches for making or breaking various circuits. It should also include means for ascertaining the amperage and voltage of the current that may flow in the circuit. In electrotherapeutics, a switchboard means the same with this addition, that it may also include means for producing one of the current varieties, such as a faradic coil, with the necessary cells or a collection of voltaic cells for producing the direct current.

53. A Typical Switchboard.—It would complicate matters too much to go into a detailed description of any of

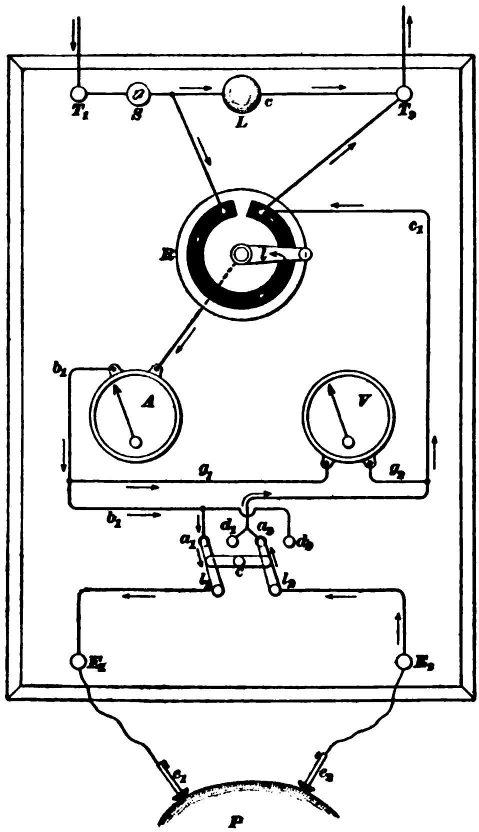


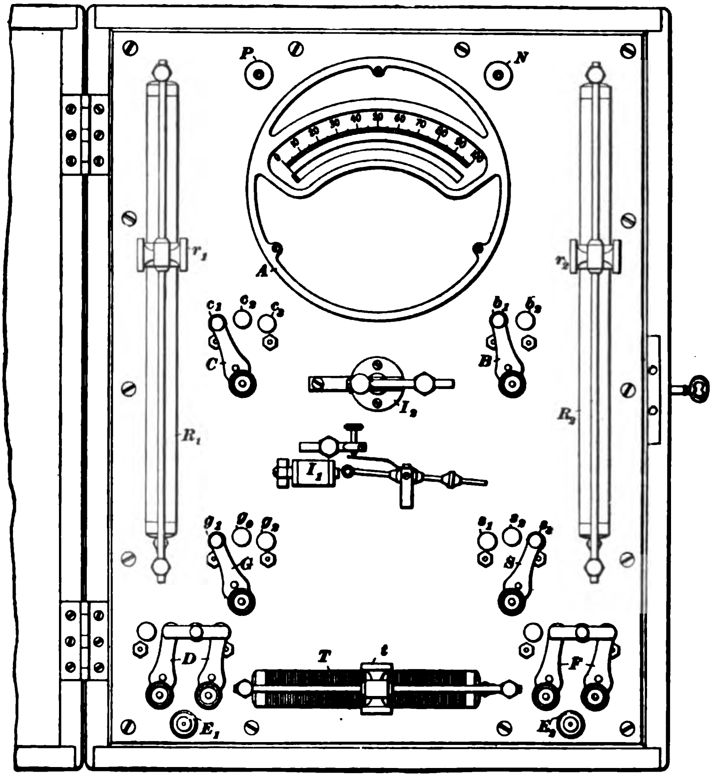
Fig. 35.

the switchboards, therefore we must limit ourselves to a general description of same. The diagram, Fig. 35, will serve this purpose. It represents a switchboard that will control and register the current delivered from a direct-current lighting circuit. T_1, T_2 are the binding-posts that connect the board with the general circuit of 110 volts. The current passes directly from one post to the other through the cut-out switch S and incandescent lamp L. Arranged in shunt with the latter is the rheostat R of about 10,000 ohms resistance. The current flowing between the posts T_1, T_2 will, therefore, divide itself between these two parallel circuits, the greater part flowing through the lamp L of about 220 ohms resistance and the smaller part flowing through the rheostat. From the latter, the current flows along the lever l to the ammeter A and from here through the conductor b_1 to the pole-changer c, which is arranged in the same manner as shown in Fig. 34 with regard to the binding-posts E_1, E_2. After flowing through the electrode e_1, patient P, and electrode e_2, the current again returns through the pole-changer, to the rheostat and other binding-post T_2, to the external circuit.

The conductors g_1, g_2 connect the voltmeter V across the conductors b_1, c_1 and will therefore indicate the electric pressure to which the patient's circuit is subjected.

For simplicity's sake we have in this instance supposed that the current was supplied from a lighting circuit. The supply may also come from a battery of voltaic cells, in which case a cell-selector and rheostat may be inserted in the circuit, or simply a rheostat. In either case the lamp L would be omitted.

54. Switchboard for Galvanic and Faradic Currents.—As an example of an efficient switchboard by means of which either the galvanic or faradic current may be supplied, we give that illustrated in Fig 36. It is made in the shape of a box, to enable the operator to carry it around from one part of the building to another, as may be necessary in a hospital, and also makes it possible to lock it and thus prevent its being handled by any one that is not familiar with its construction. The front is a panel of polished slate, to which all the various devices are directly fastened. Behind this, and firmly supported by it, is the faradic coil; likewise the dry cells for supplying the current for its primary coil. There are also four resistance-coils that act as volt selectors in the same manner as the lamps shown in Fig. 15, when the direct current from a commercial lighting circuit is used. Everything not absolutely necessary for the selection and variation of the current is put out of the way, which makes it possible for the operator to handle the board with the least amount of confusion.



Galvano-Faradic Switchboard.

FIG. 36.

55. Importance of a Good Meter.—In using the galvanic current, everything centers around the milliammeter. The latter should be above suspicion, as regards its correct indication of the current-strength, and should not be liable to change or deteriorate in such a manner as to affect its future indications. In many delicate operations the current dosage may be only a few milliamperes, and it is here important that the readings of the meter should be absolutely reliable. It should also preferably be dead-beat, in order that sudden variations may be made in the current-strength without causing the pointer to fly violently all over the scale with the possibility of striking the stops at the end of the scale and thus cause an injury to the meter.

56. Method of Applying the Direct Current.—When it is desired to use the direct current from the commercial lighting circuit, then conductors connected with the latter are attached to the two binding-posts *P*, *N*—*P* being positive and *N* negative. The switch *B* serves the purpose of making or breaking the connection between the lighting circuit and the various circuits of the board. In the position indicated, the current is cut off. The binding posts E_1, E_2 receive the conducting cords of the electrodes with which the patient is to be treated. *D* is the current-selector that must be moved to the left in order to connect the posts E_1, E_2 with the galvanic circuit.

The board is intended to be used with a 110-volt circuit. As this voltage is inconveniently large to use directly, the current is sent through four resistance-coils connected in series. Three of these coils are connected with the buttons c_1, c_2, c_3 of the volt selector *C*. This makes it possible to supply an electric pressure to the binding-posts E_1, E_2, of either 30, 60, or 90 volts. The fourth coil remains always in series with the patient. Whatever pressure is selected, the pressure at the posts E_1, E_2 may be reduced to zero by pushing the sliding contact r_1 of rheostat R_1 down to the lower end of the same. The desired current-strength may then be obtained by raising r_1 until the meter *A* registers the desired number of milliamperes.

The pole-changer *F* will give the operator the desired polarity at the posts E_1, E_2.

57. Method of Applying the Faradic Current. When the faradic coil is to be inserted in the patient's circuit, the current-selector *D* is moved to the right. The current is supplied by the dry cells back of the board, as soon as the switch G is moved from its contact with the central button g_0 either to the left or right. If pushed to the right, the rapid interrupter I_2 is set in action; if to the left, the slow interrupter I_1. The switch S determines the active length of the secondary coil, as the buttons s_1, s_2, s_3 connect respectively with the divisions containing 300, 800, and 1,500 yards of wire. The rheostat T, with contact-spring t, regulates the current from the cells through the primary faradic coil, and the rheostat R_2 with contact r_2 that of its secondary circuit, while the pole-changer F, also in this circuit, may effect a change of polarity of the posts E_1, E_2. Both rheostats R_1, R_2 are in shunt with their respective circuits.

ELECTRODES.

58. Function of Electrodes.—When electricity is therapeutically applied, the aim is to send an electric current through a given part of the human body. When thus applied the latter constitutes necessarily one part of an electric circuit while the current source constitutes the other part. So far, we have considered solely that part which contains the source with the necessary means for regulation and registration; the other part, the human body, will be considered elsewhere. There is yet a third element to be considered, the junction between these two parts. Evidently there are no means for making that intimate electric connection between them as in other parts of the circuit, and some means must be found to make a temporary connection that will, in the main, fulfil the requirement of providing a free path for the current from one part of the circuit to the other. As the body itself does not offer a metallic surface with which to connect, a substitute is found in some fluids of fairly high conductivity. This fluid is interposed and confined between the metallic terminals of the electric source and the tissues of the human body. Being a fluid, it will more or less penetrate the external layer of the various tissues and thus provide a more intimate contact and extended surface area. Where the tissues themselves provide the fluid, such as mucous membranes, a simple metallic contact surface is usually sufficient. Devices that serve this purpose of acting as an intermediary between an electric source and the human body in supplying the necessary contact-surfaces and possessing the required conductive properties are called **electrodes.**

Ordinarily the receptacle for the intervening liquid is a piece of sponge, a pad of gauze, cotton, felt, or perhaps clay or gelatine. Or it may, in the case of the hydro-electric bath, be contained in a full-sized bath-tub, or smaller tubs, when it is a question of simply treating part of the body.

59. Classification of Electrodes.—It is not the intention, at this place, to go into a detailed description of the numerous electrodes used in electrotherapeutics. They will suffer numerous variations in form to best adapt them for the immediate purpose in view, and these variations will be described under the special treatments considered in other parts of this course. The present aim is rather to call attention to the main requirements of a good electrode and the reasons for its deterioration or inefficient function.

Electrodes used for applying the current from static machines will not be considered here, because the electric pressure available in those cases is so high that in most cases no immediate contact between electrode and patient is required. It is here mostly a question of applying the galvanic, faradic, and sinusoidal currents. The electrodes utilized for this purpose may be divided in two main classes: (1) those having a metal terminal that supplies the current directly to the tissues, and (2) those that have a fluid as an intermediary. These two classes are otherwise known as *bare* and *covered* electrodes.

1. *Metal Electrodes.*—The main requirement regarding these electrodes is that they shall not be acted on chemically by the solutions that are electrolytically separated from the tissues while traversed by an electric current. Small electrodes, such as are used in the ears and similar places, are generally gold-plated, while larger electrodes have a coating of nickel. When it is required that the electrode shall cover a very extended area, sheets or strips of tin are used.

Most electrodes consist of a metal rod, which at one end terminates in that part that is to be brought in contact with the body and at the other end is provided with a binding-post to receive the conducting-cords from the battery. The metal rod is covered with some insulating material such as wood or hard rubber to prevent communication between it and the operators hand.

It has already been remarked that the positive electrode is of acid reaction and the negative of alkaline. As metals, such as brass and copper, are affected by acids, the active electrode should always be made negative, unless special reasons require that it be made positive. Being negative, it will, notwithstanding the greater current-density through it, be little affected by any chemical action; while on the other hand, the positive indifferent electrode is of so much larger area that the acid effects are little noticeable.

2. *Covered Electrodes.*—These are of many varieties. They consist mostly of a metallic frame, or skeleton, that acts as a support for some fibrous material with which it is covered. This covering serves as the receptacle, or retainer, for the fluid which fills the function of an intermediary between the metallic framework and the tissues of the body. The metal mostly used for support is perforated brass. As it oxidizes rather freely, it is difficult to keep its surface in as good condition as it should be, and perforated aluminum sheets of about No. 24 B. and S. gage would therefore be greatly preferable, as less liable to oxidation, much lighter, and of a more bright and cleanly appearance. It should be remembered that the prime function of this metal skeleton is not that of supporting the surrounding pad, but that of evenly distributing the electric current to the same. For this reason, it is of paramount importance that this metal plate has a good conducting surface, free from any metallic oxids or other impurities, which will impair its conducting properties. In some cases, the resistance that these oxids interpose in the circuit may be so great as to stop the current altogether. Carbon is also used as the conducting support, either in the form of a small ball that is surrounded by a wad of cotton or in the shape of disks or plates. As carbon does not oxidize, it has, in this respect, advantages over the metal plates.

60. Distinction is also made between an *active* and *indifferent*, or *dispersing*, electrode. An **active electrode** is the one that is applied to that part of the body where the effect of the electric current is desired.

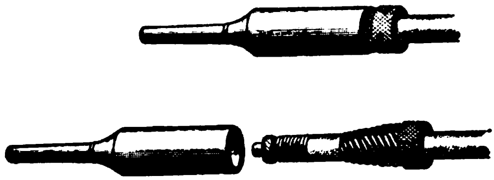
The **indifferent electrode** serves simply the purpose of completing the electric circuit, and derives its name from the fact that it ordinarily is indifferent where it is placed. It is usually of an area much larger than the active electrode, because it is desirable to disperse its action as much as possible and thereby prevent any effects on places where it is not desirable.

61. We have already mentioned that an electrolytic action is carried on by the electrodes. The products resulting from this decomposition has often a very deleterious effect on that part of the skin that is covered by the electrodes and may leave eschars that are difficult to heal. For this reason it is sometimes advisable to use *non-polarizable* electrodes. These contain mostly a small chamber filled with a solution of sulfate of zinc. Between the interior of this chamber and the tissues to be acted on, is a cover of some porous material that allows intercommunication between them. The electrolytic products will therefore not remain near the skin, but will pass through the cover into the chamber and thereby be prevented from producing any harmful action on the tissues.

Regarding the antiseptic treatment to be given the covering of electrodes, full information will be found in subsequent sections. To maintain their electrical function at maximum efficiency, the metallic surfaces that adjoin the covering should be frequently rubbed with sapolio or bon ami, and in extreme cases with fine emery paper—in order to remove any oxids that may have accumulated on them.

CONDUCTING-CORDS.

62. Conducting-Cords connect the electrodes with the switchboard or any other current source. To insure a certain mobility to the electrodes, the conducting-cords are made of fine strands of copper wire that are covered with silk or cotton. The cords should have cord-tips at either end to facilitate their easy insertion both in the binding-posts of the switchboard and the electrodes. A universal cord-tip is shown in Fig. 37, where the upper figure shows the tip and cord assembled, while the lower figure illustrates how the tip may be taken apart in order to insert a new cord in the same. When cords are subjected to sharp bends, they may, in time, break without showing any exterior signs of such. Sometimes the cause of the irregular



Universal Cord-Tips.

FIG. 37.

action of the current from a faradic coil are looked for in vain, until finally the fault is found in one of the cords.

The cord-tips are supposed to be of such dimensions that they will fit any binding-posts. Though such conditions are greatly to be desired, they are not yet, by any means, attained, and the practitioner sometimes finds himself in possession of apparatus that will not receive his cord-tips until some subsequent tinkerings have been performed.

THE HYDRO-ELECTRIC BATH.

63. Characteristics of the Hydro-Electric Bath. When it is a question of giving the electric current an opportunity to act over extended areas of the human body, the **hydro-electric bath** is utilized either for the whole body or part of same. The bath may then, in one respect, be said to perform the function of an enlarged electrode; but in some other respects it differs. This is because the body is immersed and is surrounded by water from all sides. When an ordinary covered electrode is applied, the whole current must go through it, and it alone, before it can pass into the body, as the electrode is the only path by which the current can enter. By letting a certain quantity of water completely surround the body, the water itself will offer a by-path for the current. The adjacent layers of water may be said to be in shunt with the body, and as such will be subject to laws of an ordinary shunt. That is, it will conduct a part of the current, the strength of which will depend on the resistance of the shunt relative to that of the main conductor—the body. If the fluid is of a relatively high conductivity and the body of a lower one, it is obvious that most of the current will pass outside of the body and the desired results will not be obtained. It is possible though, by means of the electrodes through which the current is sent into the bath, to more or less counteract this dispersing effect of the water and to localize the action of the current on those places where it is desirable that it should act.

CONSTRUCTION OF THE BATH.

64. Material of Bath-Tub.—It is important that the tub should not be a conductor of electricity, otherwise the whole current will circulate around the water without entering it. Even a metal bath-tub covered with an insulating coating is to be avoided, as sooner or later some parts of the coating will wear or break off, and then the current will be able to make a short circuit through the metal wall. Oak or porcelain are the most suitable materials for its manufacture, the latter being the more cleanly of the two.

65. Importance of Insulation.—Insulation is an important point that needs careful attention—particularly if the current from the lighting circuits is to be utilized. In the latter case the water in the tub must not be directly connected with the waste- or water-pipe, as either of these communicates with the ground; the current would, in case of a short circuit on the main line be able to pass up through these pipes and subject the patient to a very strong current. Therefore the necessity of having the tub entirely disconnected both from the waste-pipe and from the water-supply pipes.

66. Insulation of the Bath-Tub.—Fig. 38 gives the general arrangement of a tub that is entirely separated from any ground connection; it is in sectional elevation and represents a tub made of oak partly filled with water. *A* is the tub itself, and *B* a back rest to prevent a direct contact with the anode *a*, which is here the head, or cervical, electrode; the cathode, or foot, electrode *b* is unprotected. The dimensions of the head-electrode may be 11 × 12 inches, and of the foot-electrode about 9 × 14 inches. The stopper is marked *d* and is inserted in the upper part of the short outlet tube *e*; consequently, there is no direct connection with the sewer-pipe *g*. The pipe *e* conducts the water into a shallow basin *f*, from which it flows

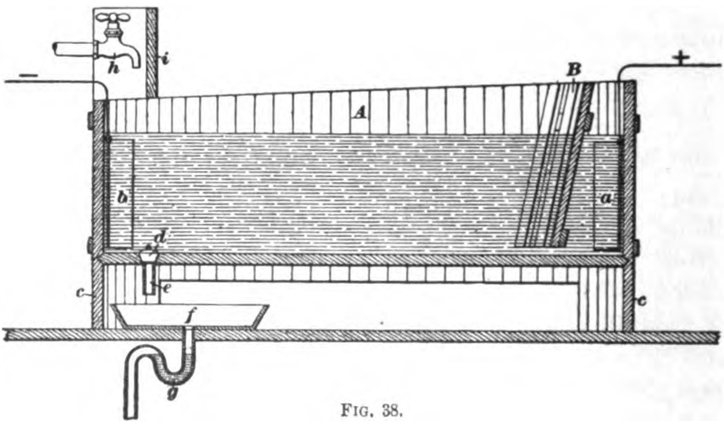


Fig. 38.

into the pipe *g*. Around the supply pipe *h* is built some kind of a guard *i*, to prevent a direct contact with the tube *h* on the part of the patient; otherwise, he might, under certain conditions, be exposed to a short circuit. To give room and access to the basin *f* and also to give free circulation of air under the tub, the latter is supported by legs *c*, *c*.

When the current is supplied to the bath from a local current source, as for instance, an independent dynamo, a voltaic battery, a faradic coil, a sinusoidal apparatus, or a transformer, then these precautions are unnecessary and an ordinary enamelled or porcelain bath-tub provided with the customary plumbing connections, may be utilized.

MONOPOLAR AND BIPOLAR BATHS.

67. Bipolar Bath.—A bath may be *monopolar*, *bipolar*, or *multipolar*. So far, the baths considered have been of the **bipolar order,** and to this class the multipolar baths may also be said to belong, as a multiplication of poles simply means a subdividing of the anode and cathode.

68. Monopolar Bath.—By **monopolar bath** is not meant a bath with one active pole only, but rather a bath that contains only one electrode submerged in the water while the other is exterior to same. The bath-water is therefore of one polarity, either positive or negative, and may be considered as an electrode that completely envelops the body and thus provides a very large surface contact.

69. Difference Between Monopolar and Bipolar Baths.—There is quite a difference between a monopolar and a bipolar bath. A current is passing through the latter, of which the body receives a certain portion, depending on its position and size, some parts receiving more than others; how much, as has been shown, it is not always easy to tell.

In the monopolar bath, the conditions are entirely changed. Here the exterior electrode, for instance, the anode, is placed in contact with the body at any desirable point, and at this point the current is compelled to enter—here only, and what is more, the whole current. There is, then, no longer any uncertainty of where the current acts and in what strength. In leaving the body again, the current is diffused over a very large area; in fact, over the whole submerged part of the body.

The monopolar bath may therefore localize the action of the current to one particular spot, if desirable, while the bipolar bath gives a general distribution of electricity through the whole body. The exterior pole, in a monopolar bath, may consist of a metal rod, covered with wash-leather and placed across the widest part of the bath. This rod is connected, by a well-insulated wire, to one of the terminals of the electric source; when the patient grasps the rod in his hands, the current passes through his arms and trunk to the water.

70. Paddle Electrode.—If it is desirable to localize the action of the current to one particular spot, a **paddle electrode** is used. This consists of a metal electrode whose dimensions are about 5 in. × 7 in., and which is provided with a long handle of insulating material. The operator can, by means of this electrode, concentrate the action of the current on any desirable part of the body, either by holding the electrode stationary against the part in question, or by imparting to the electrode a circulating motion, if it is desirable to affect a larger area.

71. Other Electrodes.—In the **multipolar bath** there is, besides the electrodes at the head and the foot of the bath, also a **lumbar electrode,** usually 6 in. × 10 in. By means of these three electrodes, various combinations may be made. For instance, the lumbar may work in conjunction with the head, or as it is usually called, the cervical electrode, and the foot-electrode. Or, the cervical may be placed opposite the lumbar electrode, and both act as lateral electrodes. If the foot-electrode is removed and the lateral electrodes are of opposite polarity, the current will travel across the bath only, and act on the special organs situated in its path.

A further variation may be made by covering the lumbar electrode with a light wooden framework and utilizing it as a *gluteal electrode.* By letting the patient sit on this and use it in conjunction with the cervical and foot-terminals, or with the latter alone, a further localization of the current may be accomplished.

It should be remembered that the quantity of current which the body will receive, also depends on its proximity to the electrodes, so that this provides a further means for giving a local as well as a general application of the electric current.

72. Stationary and Movable Electrodes.—The various electrodes used in a multipolar bath may be either *stationary* or *movable.* In the former instance, the walls of the bath are usually perforated and the insulated wires passed through these openings. The conducting wires lead to a common switchboard, where, by means of plugs, any electrode may be thrown in or out of action. This arrangement of stationary electrodes has certain advantages from the fact that the electrodes are always ready for action and need no additional handling. At the same time, there are certain drawbacks inherent in the system. For one thing, the arrangement is less flexible than with movable electrodes, unless their number is increased; then again, the perforation of the sides of the bath leads sooner or later to a leakage. But the greatest disadvantage results from the numerous electrodes constantly situated in the bath, some of which at times are idle and, as such, cause complications that it is difficult to avoid.

The reason for this is that those electrodes that are idle are at the same time parallel with the submerged body and constitute a shunt to the same. As such they will divert part of the current. In other words, the electrodes serve to short-circuit the other electrodes, thus preventing the body from receiving the current intended for it.

For these reasons it is preferable to have removable electrodes and to have them supported by means of metal strips or wires that pass over the edge of the tub instead of through the walls.

73. Switchboard for the Hydro-Electric Bath.—To facilitate the changes in polarity of the several electrodes, the switchboard shown in Fig. 39 may be used to advantage. Plate I is for the head, Plates II and III for the left and right sides, respectively, and Plate IV for the foot-electrode. When the plugs are placed, as shown in the illustration, it would mean that the head-electrode is of one polarity, and the left side, right side, and foot of another polarity. By taking out all the plugs and inserting one in

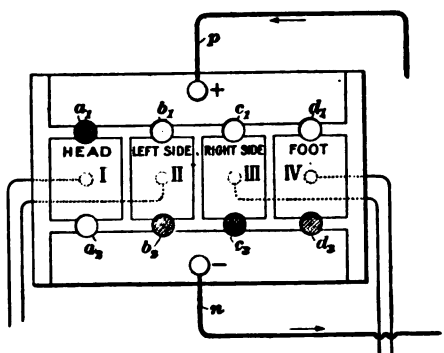


FIG. 39.

hole b_1 and another in c_2, the whole current would go from the left side to the right. In the same manner, other current paths may be effected by arranging the plugs in different ways and thus localizing or accentuating the action of the current on certain parts.

74. Construction of the Electrodes.—The electrodes should be made of bright metal that does not oxidize too freely; for this purpose aluminum sheets, of, say, No. 24 B. & S. gauge seem the most serviceable. They can be easily cut to the desired dimensions, do not oxidize, and look clean and bright. If necessary, they may be covered with a light lattice frame, which can be removed when the electrodes are to be cleaned.

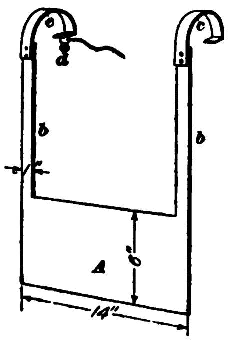


FIG. 40.

The form of the electrode may be as shown in Fig. 40, which represents a lumbar electrode of the dimensions given. *A* is the electrode proper, *b*, *b* the strips from which it is suspended and which are riveted to the hooks *c*, *c*. The latter rests on the edge of the tub and may be slid along the same into any desired position. At *d* is a binding-post for connection with the conducting-cord.

75. Current-Density.—By **current-density** is meant the current-strength per unit of cross-sectional area of a conductor; in the present case, the square foot may be taken as the unit of area. We see, then, that the density must vary directly with the current-strength and inversely with the area of the transverse section. That is, if the strength of the current is constant, an increase in sectional area of the conductor will decrease the density of the current per unit area.

If D stands for density of current, C for current-strength, and A for the sectional area, then $D = \frac{C}{A}$. Let, for instance, the current-strength through a body be .266 ampere and its sectional area 3 square feet. The density through same then is $D = \frac{C}{A} = \frac{.266}{3} = .089$ ampere per square foot.

76. While speaking of density, it may here be of interest to mention a peculiar variety of electric bath. It has been devised for the purpose of avoiding the loss of current caused by the latter passing through the water in parallel with the body. A diaphragm of rubber is placed across the bath enclosing the human body, thus dividing the bath in two. The current will then, at the point where the diaphragm is situated, pass wholly through the body, because it is unable to pass through the diaphragm. It is true that by this arrangement the whole current will go through that part of the body inserted in the diaphragm and that it here will be of maximum density. But as a consequence the density through other parts of the body will be determined by the tolerance of that in the diaphragm, and the rest of the body will therefore necessarily be traversed by a current of low density. Very similar results may be obtained by arrangements such as the monopolar bath.

VARIETIES OF CURRENTS USED FOR HYDRO-ELECTRIC BATHS.

77. Direct and Alternating Currents.—The electric current in nearly all its varieties is used for hydro-electrical purposes. We have first the ordinary direct current, as furnished by a voltaic battery or by the lighting stations; then the pulsatory current, as delivered by some sinusoidal apparatus in which the alternating current can be changed into unidirectional. The faradic current from an induction-coil or the alternating current from a sinusoidal machine, or from a transformer fed from some lighting circuit, are also employed.

78. If the direct current is to be supplied by means of voltaic cells, it is of importance that the latter are of good size, so as to be of sufficient capacity and able to run for a long period without renewal. The method of selecting the proper number of cells and connecting them has already been explained. The current may be regulated by means of a rheostat, of a size large enough not to heat, or by means of a double-handed cell-selector. The rheostat should be able to regulate a current of 300 milliamperes without overheating, and both the rheostat and cell-selector should be so made that the current can be entirely shut off.

79. Measuring Instruments.—For proper regulation of the current-strength through the bath a milliammeter is necessary that will register up to 300 milliamperes. Sometimes a voltmeter is also convenient when it is a question of ascertaining the voltage of the battery or the separate cells. Some milliammeters are so made that, by the addition of a suitable resistance, it may be changed into a voltmeter.

80. Current From Lighting Circuits.—When the direct current is taken from the lighting circuit, the bath must, as has already been said, be well insulated. In addition to disconnecting the bath from the waste and supply pipes, it should be placed either on plates of vulcanized rubber or glass.

81. Current From Induction-Coils.—When the current from an induction-coil is used, the latter should be one that has an interrupter with a smooth action; its speed should be variable between wide limits, say between 1,000 and 4,000 interruptions per minute.

So-called bath coils, which simply consist of a primary coil, are also used for the electric bath. They depend for their action on self-induction alone, and belong, therefore, strictly in the class of the direct-interrupted current, as the latter does not change in direction. Its self-induction is high; the make-current is therefore very weak, and the break-current predominates to such an extent that it is really the only active one. Its regulation is accomplished by subdividing the coil and throwing part of it out of action, if the current-strength is to be reduced.

82. Current From Alternators.—The alternating current from the lighting circuits has been used quite extensively in operating transformers intended for the supply of a sinusoidal current. Some practitioners prefer to use the supply current for the operation of a motor and let the latter drive a sinusoidal machine. This arrangement gives an opportunity for regulating the voltage as well as the frequency of the alternations.

DYNAMOS AND MOTORS.

DYNAMOS.

FUNDAMENTAL PRINCIPLES.

83. Conversion of Mechanical Into Electrical Energy.—In the voltaic cell we have seen a source of electromotive force, in which chemical energy was changed into electrical energy. Under certain conditions this source was found satisfactory, but where the supply was to be continuous and the output in watts large, it would, in addition to being inconvenient, also be very expensive. Under these conditions the advantage lies with a source of electromotive force in which mechanical energy is changed into electrical energy.

In *Magnetism and Electromagnetism*, when treating of electromagnetic induction, we observed that a wire moving across a magnetic field, or vice versa, had an E. M. F. created in it. This was taken advantage of in the induction-coil by changing a low E. M. F. into a high one, and was also utilized in the sinusoidal apparatus for the production of an E. M. F. The latter machine properly belongs in the class where mechanical energy is changed into electrical; but, as the power consumed is so small, and its field of usefulness limited mostly to that of the induction-coil, it was treated in conjunction with the latter.

Fig. 33, *Magnetism and Electromagnetism*, showed the effect of moving a conductor across a magnetic field. It would naturally suggest the idea that a machine built on that principle could be advantageously used for generating an E. M. F. on a larger scale by adding more conductors and moving them at high speed.

Since it is, of course, impossible to constantly supply new conductors, provision must be made for returning the conductors to their original positions, and let them repeat their motion through the magnetic field without interfering with the action of the machine.

These conditions are complied with if the conductors are arranged along the curved surface of a cylinder or radially along the sides of a disk, and if either of these are set in rotation in a magnetic field. We will consider the cylindrical form only, as shown in Fig. 41.

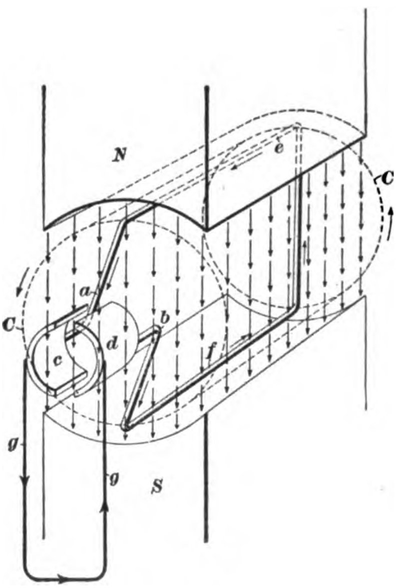


FIG. 41.

Here we have a conductor *a e f b* bent along the surface of a cylinder, shown in dotted lines, and rotating with it in the direction shown by the arrows. The ends of the conductor are joined to the segments *c*, *d*. *N* and *S* are the poles of the magnet, and, as *N* is the north pole, the lines of force will pass in the directions indicated by the arrows on the dotted lines. From the rule given in Art. 54, *Magnetism and Electromagnetism*, we find that the direction of the E. M. F. induced in the lower part *f* of the conductor is as indicated by the arrow, and we also find that the induced E. M. F. in the upper part of the conductor *e* acts in the opposite direction. The result is that the two electromotive forces act in the same direction, so far as the conductor is concerned; that, therefore, the total E. M. F. will be a sum of two; and that there is a tendency to start a current in the direction of this E. M. F. If, now, a conductor *g* is held, as indicated, against the segments *c*, *d*, a current will flow through the conductor as indicated.

84. Coil and Commutator.—To increase the action of the machine, wind the conductor several times around the cylinder, each convolution adding to the E. M. F.; it constitutes then what is called a **coil.** It is also evident that it would be a waste of space to let the rest of the cylinder lay idle; that, in fact, it would be natural to provide the whole circumference with conductors, and that each would be connected with segments similar to *c*, *d*, but that the latter would have to be made correspondingly narrower, so as to allow space for the rest. These segments would all be insulated from one another, and form a cylinder called a **commutator,** so named because it commutes currents running in opposite directions into currents running in the same direction, and under certain conditions combines these currents into one uniform current.

Instead of making contact with the commutator by means of a conductor *g*, it is customary to provide two broad plates, either of carbon or of laminated copper, called **brushes,** and let the terminals of the machine be connected with the supports of these brushes.

85. The machine described has one great drawback; there is only one conductor at a time in communication with the brushes. Any electromotive forces that may be generated in the other conductors are useless; they cannot start currents, because their segments are insulated from one another, like *c*, *d*, and, therefore, their circuits are open. Even could currents flow, they would be unable to reach the brushes, and would simply waste their energy in their respective circuits. To eliminate this great fault, all the conductors or coils are connected with one another, constituting one large coil.

86. Armature.—As yet, no mention has been made of the cylinder *C*, indicated by dotted lines. It could be made of any material, simply acting as a support for the conductors, but it is always made of laminated iron. It is made of iron, because iron is a good magnetic conductor, and thus, practically, is a continuation of the magnetic pole-pieces *N*, *S*; and it is laminated in order to avoid the starting of Foucault's current.

This combination of the conductors and an iron cylinder or drum is called an **armature.**

It is not necessary that the conductors be supported by a cylinder; they may also be wound around a ring, as shown in Fig. 42, and then constitute a **ring armature,** while the former is called a **drum armature.** The iron ring or drum is the **core.**

87. Ring Armature.—In Fig. 42, we see all the coils a_1, a_2, etc. connected with one another, constituting one coil; we

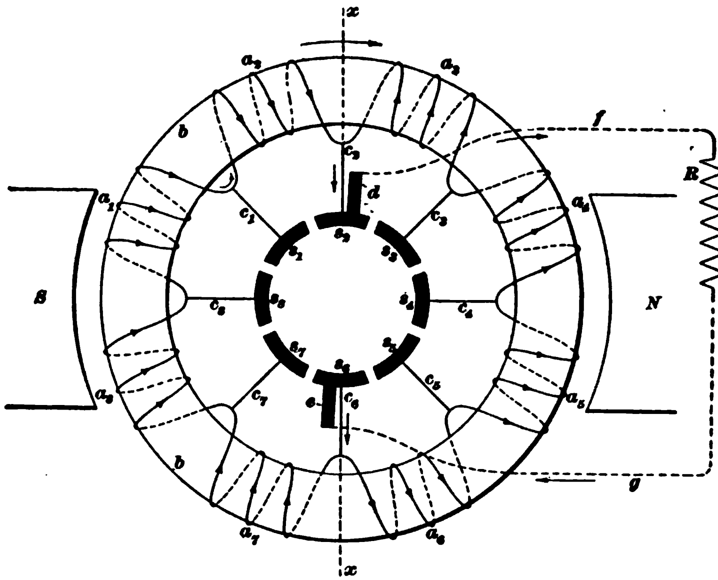


Fig. 42.

also see the connectors c_1, c_2, etc. connecting the junction of the coils with the commutator segments s_1, s_2, etc. *N* and *S* are the pole-pieces; *N* being the north pole, the lines of force will pass from right to left. The armature-core is marked *b*, and is rotating in the direction indicated by the arrow.

From what has been previously said on the subject, we should easily find that the directions of the induced E. M. F. in the various coils are as indicated by the arrows. We notice now a peculiarity which, at first glance, would seem to make the whole machine inoperative, that the directions of the electromotive forces on one side of the dotted line xx are acting in opposition to those on the other side. But, after some consideration, we find that the two halves of the armature are, in reality joined in parallel, and that whatever currents are flowing in either half, combine at the connector c_2, pass through the latter into the segment s_2, and from there through the positive brush d into the conductor f. After passing through the external resistance R, the current returns through the conductor g, into the negative brush e, then through the segment s_6 and the connector c_6, when it divides, one half of the current flowing through the coil a_6 and the other half through the coil a_7. From either of these coils, the currents continue their upward flow; but it must be remembered that in the next moment the coils a_6 and a_2 will pass the line xx, called the **neutral line,** and that then the current will flow through them in opposite directions. In fact, in each coil the direction of the current flowing through it will be reversed twice for each revolution of the armature.

88. It was stated in *Magnetism and Electromagnetism* that the E. M. F. produced in a conductor increased in proportion to the density of the field and the speed of the conductor in a direction at right angles to the lines of force. Neither of these factors is constant in regard to the armature of Fig. 42. The coils a_4, a_5, a_1, and a_8 are passing through a denser field than the coils a_2, a_3, a_6, and a_7; the E. M. F. of the former coils will therefore be higher than that of the latter. An additional detriment is that the last-named coils no longer travel in a direction at right angles to the lines of force, but more or less parallel to them, and that, therefore, when approaching the neutral line, smaller and smaller electromotive forces will be produced in them.

89. Armature Compared With Cells in Parallel Series.—How these electromotive forces of varying heights and directions combine so as to produce one current is shown by means of Fig. 43. We have here 10 cells, arranged in two parallel series of 5 cells. There are, therefore, 5 cells on either side of the neutral line xx, the electromotive forces of the cells at the left running in opposition to those of the cells at the right. The effect is that two currents of electricity will flow, one on either side of the neutral line, and that they will meet at c_1, where they unite into one current of double the amperage; it will then flow through the segment s_1, into the positive brush d, the conductor f, and through the external resistance R. From here it will again return through the conductor g to the negative brush e, pass through the segment s_6, when it will divide again into two separate currents flowing through the cells on either side of the lines x, x to the connector c_1.

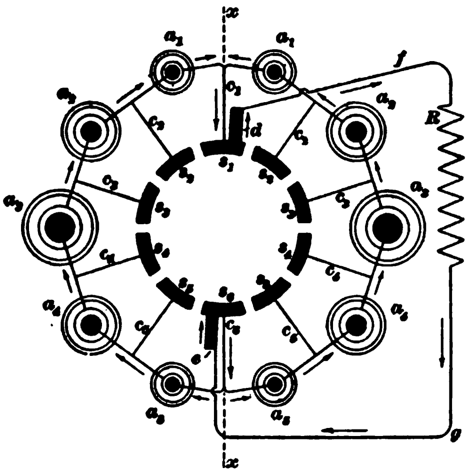


FIG. 43.

If the current, instead of dividing into two branches, had to pass through all of the 10 cells, the loss in voltage would be 10 volts, if we suppose that the internal resistance of a cell is .1 ohm and the current-strength 10 amperes. In the arrangement indicated in Fig. 43, the total resistance of the battery would be (see *Direct Currents*):

$$r' = \frac{s \times r}{p} = \frac{5 \times .1}{2} = .25 \text{ ohm},$$

and the loss in voltage,

$$E = C \times r' = 10 \times .25 = 2.5 \text{ volts},$$

which is one-quarter of the drop with all the cells in series.

It was shown that some of the coils in Fig. 42 developed a higher E. M. F. than others. This has been indicated in Fig. 43 by increasing the size of the cells corresponding in position to those of the coils when having their maximum

E. M. F.; but this must not be understood to mean that an increase of the size of a cell increases its E. M. F. In this instance it must simply be taken as a graphical representation of the relative electromotive forces in the various cells.

90. The diagram in Fig. 43 shows the result of connecting all the coils in series and connecting all the junctions with the commutator-segments. We see that each cell adds its E. M. F. to that of the preceding cells; the same is done by the coils in Fig. 42. It is also evident from Fig. 43 that the connections between the segments and the coils have no influence on the flow of current, and no function to perform, except in that instance when the segments pass under the brush. The segments s_2, s_3, s_4, and s_5, though joined to the connectors c_2, c_3, etc., cannot transmit any current in the positions there indicated, because, for the moment, they are insulated from the rest of the circuit; all the connectors and segments, except those marked c_1, c_6 and s_1, s_6, might therefore be removed without affecting the operation of the dynamo or cells, so far as the position indicated is concerned. Of course, when the armature revolves, all the connectors and segments subsequently come in action.

91. Action of a Dynamo.—We are now able to study an assembled view of a **dynamo** and understand its action in general. In Fig. 44 a dynamo is shown in a diagrammatical view. *A* is the armature, *c* the commutator, *d* and *e* the brushes, and *h* the shaft that supports and drives the armature. The shaft is supported in bearings, not shown in the drawing, at both of its ends. *N* and *S* are the pole-pieces, which receive their magnetism from the electromagnets *E*, E_1, *k*, *l* being the coils, and *i*, *j* the cores of the

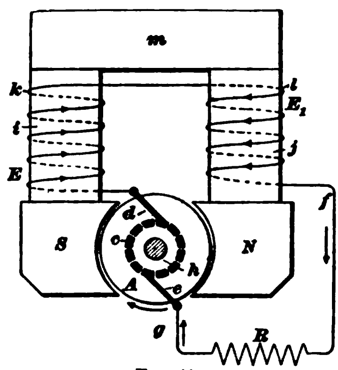


FIG. 44.

electromagnets. The upper ends of the cores are connected by an iron block *m* called a **yoke.**

The current leaves the positive brush *d* and passes directly into the coil *k*, then from this into the other coil *l* and through the conductor *f* into the external circuit *R*. From here, it returns through the conductor *g* and the negative brush *e* to the commutator *c* and the armature *A*. The electromagnets or **field-magnets** as they are usually called, are therefore magnetized by the dynamo itself, and the latter is therefore said to be *self-excited.* If the exciting current of the field-magnets is supplied from some outside source, it is *separately excited.*

CLASSES OF DYNAMOS.

92. Series and Shunt Dynamos.—When the whole current from the armature goes through the field-magnet coils, and they, so to speak, are connected in series, the dynamo is a **series-dynamo,** Fig. 44. If the field-magnet coils and the external circuit are connected in parallel, and therefore only part of the whole current goes through the field-magnet coils, which, in that case, usually are of high resistance, then it is a **shunt dynamo,** Fig. 45. Here the current divides into two parts, the smaller passing directly into the field-magnet coils F, F_1 while the balance goes into the external circuit.

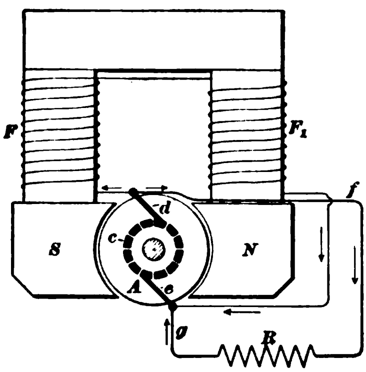


FIG. 45.

93. Compound Dynamo.—When the coils are partly in series and partly in shunt, we have a **compound-wound** dynamo, as shown in Fig. 46.

94. Difference Between Series and Shunt Dynamos. These variations in combining the coils with the armature are for the purpose of regulation, and are determined by the use for which the dynamo is intended. When, as in Fig. 44, the whole current goes through the field-magnet coils, the flow through the latter will be affected by any variation of resistance in the external circuit *R*. An increase of resistance will diminish the amperage of said coils and also the strength of the magnetic field. In Fig. 45 the conditions are different. Increasing the external resistance causes an increased flow through the coils F, F_1, and therefore strengthens the magnetic field. The E. M. F. of the armature will then increase, and it will be able to send the same current through an increased resistance, if this remains within certain limits. Fig. 46 is a combination of both, and a dynamo of this character is able to regulate itself within wide limits.

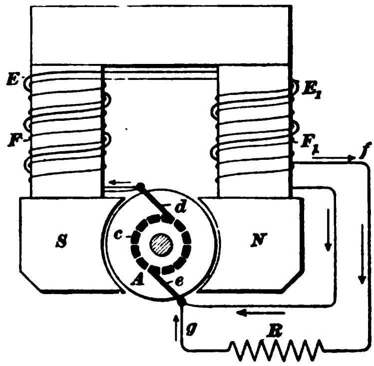


FIG. 46.

95. Alternators.—The dynamos so far considered deliver a continuous current, because the commutator rectifies the various currents in such a manner that they run in the same direction. The dynamo, then, in reality provides an alternating current. If we therefore excite the field-magnet coils from some exterior source, remove the commutator, and replace it by two simple contact-rings with brushes, we would, if the armature is properly wound, receive an alternating current from the brushes. The machine would then no longer be a direct-current, but an alternating-current dynamo, or what is called an **alternator.**

MOTORS.

96. General Principles.—The effects produced in a conductor moving in a magnetic field were described in *Magnetism and Electromagnetism*. If the conditions there represented be reversed and a current sent through the conductor while it is situated in a magnetic field, what would be the result? The conductor would move, but in a direction opposite to that which would produce an E. M. F. acting in the same direction as that of the current now flowing. For instance, if, in Fig. 47, the conductor were moving across the field in the direction indicated by the arrow, an E. M. F. would be created that would tend to send a current down through the paper. If, on the other hand, it is intended to move the conductor in the same direction by means of a current, sent through it from some external source, the current must be sent through it in an upward direction. The illustration will show the reasons for this. It is observed that the lines of force, encircling the conductor, and which are produced by the upward passing current, on one side travel in the same direction as the lines of force belonging to the pole-pieces *N*, *S*; a repulsion will therefore take place, as explained in *Magnetism and Electromagnetism*. On the other side, the lines of force travel in opposite directions and an attraction will be effected. Both of these forces tend to move the conductor in the direction indicated by the arrow. This reaction between an active conductor and a magnetic field is the principle on which an **electric motor** is based.

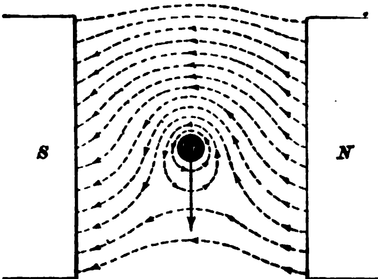


FIG. 47.

It is therefore possible to change a dynamo into an electric motor by supplying it with a current through the brushes; and, conversely, it is also possible to change an electric motor into a dynamo by supplying it with mechanical energy through the shaft.

97. Counter-Electromotive Force.—As soon as a motor-armature begins to rotate, it tends to act as if belonging to a dynamo, and begins to create an E. M. F. in opposition to that which sends a current through the brushes. This E. M. F. is called a *counter* E. M. F., and it is clear that the E. M. F. applied to the terminals must at least be equal to the counter E. M. F. plus the fall of potential in the armature.

98. Uses of Dynamos and Motors.—Dynamos are not used as frequently in electrotherapeutics as voltaic batteries, the latter being more convenient when only small units of electric energy are required. Sometimes, when larger volumes of current are needed, and electric circuits used for city lighting are at hand, these circuits may be utilized for operating an electric motor, while the latter again may furnish the necessary power for running a small dynamo. The high voltage of the lighting mains, which usually is either 110 or 220 volts pressure, may in this manner be changed into a voltage sufficiently low to be used in connection with an electric cautery.

99. As there are dynamos that produce continuous, and others that produce alternating, electromotive forces, so there are motors capable of using either of these electromotive forces, though, as a rule, a motor built for one of these varieties of E. M. F. is unable to be run by the other. It is also to be noticed that a motor is designed for a special speed and E. M. F., and, when these conditions are fulfilled, it is showing its highest efficiency. If compelled to run at other speeds or with higher or lower electromotive forces than those for which it was intended, it is likely to run at a certain disadvantage and be unable to utilize as much of the power supplied as it otherwise would. A motor may also be operated by means of a storage or a primary battery, and in any of these cases its speed is regulated by means of a suitable rheostat.

UNITS.

FUNDAMENTAL UNITS.

100. The **units** used in electricity and magnetism have partly been explained at different times, but it is advisable to repeat the definitions already given and to add others, for the sake of easy reference, and in order to show more clearly the relation and derivation of the various units.

The units are divided into the following subdivisions: fundamental units, derived units, electrostatic units, magnetic units, electromagnetic units, and practical units.

The absolute and practical units are based upon the three **fundamental units** of *length*, *time*, and *mass*, which are defined as follows:

101. Unit of Length.—The **centimeter,** or the **unit of length,** represents $\frac{1}{1000000000}$ of the distance from the pole to the equator on the surface of the earth, and is equal to .3937 inch, or 1 inch equals 2.54 centimeters, nearly. A **square centimeter** is the area contained in a square, each of whose sides is 1 centimeter in length; 1 square centimeter equals .155 square inch, or 1 square inch equals 6.45 square centimeters, nearly. A **cubic centimeter** is the volume contained in a cube, each of whose edges is 1 centimeter in length; 1 cubic centimeter equals .06102 cubic inch, or 1 cubic inch equals 16.387 cubic centimeters.

102. Unit of Mass.—The **gram,** or the **unit of mass,** or *quantity*, of *matter*, represents the quantity of matter contained in a cubic centimeter of pure water at the temperature of its maximum density, which is 4° C., or 39.2° F., and is equal in weight to 15.432 grains.

103. Unit of Time.—The **second,** or the **unit of time,** represents $\frac{1}{86400}$ of a mean solar day.

104. Absolute, or C. G. S., Units.—The system of units derived from these are named the **absolute,** or **C. G. S., system,** to distinguish it from other systems based on other fundamental units.

105. Derived Units.— From these fundamental units the following secondary units are derived:

The **unit of velocity,** or the rate at which a body changes its relative position, is determined by dividing the distance in centimeters through which a body travels by the time in seconds required to travel that distance. The unit of velocity is, therefore, 1 centimeter per second.

The **dyne,** or the **unit of force,** is that force which, by acting upon a mass of 1 gram for 1 second, can give to it a velocity of 1 centimeter per second.

The **erg,** or the **unit of work,** is the amount of work performed when a force of 1 dyne is overcome through a distance of 1 centimeter. It has already been stated that the practical unit of work in electrical measurements was the **joule;** 1 joule is equal to 10,000,000 ergs.

The **unit of power,** or the rate of expending energy, is 1 erg per second. Consequently, as the watt is equal to 1 joule per second, it must also equal 10,000,000 ergs per second.

106. Electrostatic Units.—The following units have no special names:

The **unit quantity** is a quantity of electricity that is able to repel another similar and equal quantity with a force of 1 dyne at a distance in air of 1 centimeter.

The **unit potential** is that potential which requires the expenditure of 1 erg of work to bring a unit quantity of electricity from zero potential to that potential.

The **unit electromotive force,** or **difference of potential,** exists between two points if a unit quantity of electricity will do 1 erg of work in passing from one point to the other.

in possession of a high resistance, with the resultant loss of voltage. The resistance must therefore be made as low as possible; in fact, so low that if the instrument is in circuit for days there would be no perceptible heating of its coils. This we also find to be the case with efficient meters; thus, for instance, a 15-ampere Weston ammeter has an internal resistance of .0022 ohm. When measuring a 10-ampere current, the drop ($C \times R$) is .022 volt, and the watts expended ($C \times E$) $= .22$, or about $\frac{1}{3400}$ horsepower.

33. With the voltmeter, the requirements are exactly the opposite; the resistance must be as high as possible, consistent with an efficient action of the instrument. If the resistance of the voltmeter were as low as that of the milliammeter, the greater part of the current would pass around the battery through the conductors b, b and would thus act as a short circuit. The resistance of a Weston voltmeter is about 19,000 ohms. Measuring 110 volts, the instrument would take $\frac{110}{19000} = .0058$ ampere, nearly, with a consumption of energy of .638 watt, nearly, or about $\frac{1}{1200}$ horsepower.

34. It may be suggested that the voltmeter in the position indicated in Fig. 24 should also be able to act as an ammeter by using an additional scale, it being claimed that the current is proportional to the pressure in volts. But it must be remembered that while the current-strength depends on the pressure it also depends on the resistance. For instance, let the resistance R, Fig. 24, be 50 ohms and the current-strength 500 milliamperes; then the required voltage would be $C \times R = .500 \times 50 = 25$ volts. The voltmeter would indicate this pressure, but we see at once that this E. M. F. would also be sufficient to send a current of 2 amperes through a resistance of 12.5 ohms, in fact, these two factors may vary between wide limits, so long as their product remains 25 volts. It is seen, therefore, that, for a voltmeter to indicate amperes, it must be in circuit with a constant or known resistance. This principle is made use of in the Weston ammeter, which makes it unnecessary to let the whole current go through the movable coil. The latter is connected in parallel with a short, thick piece of copper or some alloy (see a, Fig. 25) so that only a small part of the current passes through the coil, and the resistance of the instrument is extremely low. The ammeter is then more in the position of a voltmeter in parallel with a circuit of constant resistance, and now in reality measures the loss of voltage in the piece of copper a, where a_3 and a_4 are the two ends of the circuit, C the moveable coil, and S, S the conductors connecting the coil in parallel with the main circuit. The loss of potential in a will now be in direct proportion to the strength of the current through the strip a; and, as this loss determines the difference in potential between a_3 and a_4 on which the current through C depends, it is clearly seen that this current is directly proportional to the main current. Thus, while the coil C might operate as a voltmeter for the local conductor a, it will also serve as an ammeter for the whole circuit of Fig. 24, if properly calibrated.

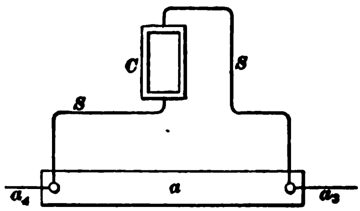


FIG. 25.

35. We then come to the conclusion that ammeters and voltmeters are in reality both ammeters; that is, they are instruments actuated by an electric current passing through a movable coil placed near a stationary magnet, or through a stationary coil acting on a movable magnetic needle. In the ammeter proper, the strength of this current depends on the E. M. F. and the resistance of the whole circuit of which the ammeter forms a part; it may also depend on a certain fixed portion of the total current for its operation, when the ammeter constitutes part of a parallel circuit.

36. In the voltmeter, the strength of the actuating current depends on the difference of potential between the points to which it is attached and the resistance of the local circuit formed by the voltmeter and its connections. We see, then, that the voltmeter is similar to an ammeter when this is provided with a local resistance, as shown in Fig. 25.

37. An Ammeter Changed Into a Voltmeter.—An ammeter of this class should therefore be capable of being transformed into a voltmeter by adding enough resistance to retain the original calibration, but reading volts instead of amperes. An example will illustrate this.

A milliammeter has a resistance of 20 ohms. If the meter is to serve as a voltmeter and the divisions in milliampers are to be read as volts, what external resistance must be added?

It is supposed that the ammeter at present measures up to 1 ampere. The resistance being 20 ohms, it requires an E. M. F. of $C \times R = 1 \times 20 = 20$ volts to bring the pointer to indicate 1,000 milliamperes. To be capable of registering 1,000 volts, the resistance must be increased to 1,000 ohms, as then, according to formula $E = C \times R$, 1,000 volts = 1 ampere $\times$ 1,000 ohms. The required addition to the present resistance is therefore $1,000 - 20 = 980$ ohms.

If the instrument shall read to 100 volts only, then, placing $E = 100$ volts, we have $R = \frac{E}{C} = \frac{100}{1} = 100$ ohms, and the needed addition will be $100 - 20 = 80$ ohms. In this instance every 10 divisions of milliamperes will represent 1 volt.

38. Difference Between Ammeters and Voltmeters. Before leaving the subject of ammeters and voltmeters, there is yet one point to mention, which is not always understood. Why is it, for instance, that an ammeter can be short-circuited with impunity, but cannot be removed from the circuit, while a voltmeter must not under any circumstances be short-circuited, but may be disconnected? Let the diagram in Fig. 26 show a voltaic battery combined with an electric bath. The resistance of the circuit is 90 ohms, the E. M. F. 30 volts, and therefore the current $C = \frac{E}{R} = \frac{30}{90} = .333$ ampere. B is the voltaic battery, a_1 the conductor sending the current to the bath C, and a_2 the return circuit. The milliammeter A is placed in series with the conductor a_1, and the voltmeter V in parallel with the bath by means of the conductor $b\,b$. It is now seen that the whole current passes through the milliammeter A before it reaches the bath, and that by disconnecting this instrument the circuit will be broken and the current stop its flow. If, on the other hand, the milliammeter be short-circuited by means of the additional conductor a, it will have no influence on the circuit as a whole, the resistance of the instrument already being so low as to be left out of consideration, but will rather have the effect of removing the instrument from the circuit.

39. With the voltmeter, we find the opposite to be the case. Here a removal of the voltmeter would leave the rest of the circuit unaltered, and the current would continue to flow through the bath; but let the voltmeter be short-circuited by means of the conductor b_1, then the conductor b would no

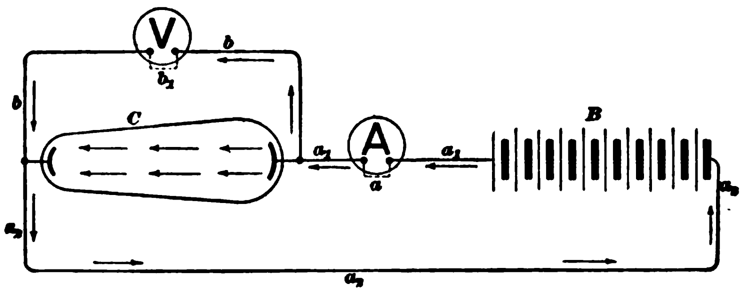


FIG. 26.

longer be limited in its conductivity by means of the high resistance of the voltmeter, and would tend to carry the whole current of the battery. It would, therefore, short-circuit the bath and consequently also the battery, and would very likely injure the latter; otherwise, the damage might be little. When it comes to circuits with higher voltage and amperage; as, for instance, in a lighting circuit, the consequences would be more serious.

In Fig. 27 we have, for instance, the conductors a_1 and a_2 leading to a combination of incandescent lamps L in a house. The lamps are all placed in parallel and the ammeter A inserted in the conductor a_1, while the voltmeter V, by means of wires b, b is connected with both conductors, and therefore is in parallel with the lamps. If, now, the ammeter be again short-circuited by the wire a_3, it will have no effect on the circuit, but will simply throw the ammeter out of action; whereas removing the ammeter altogether, before being short-circuited, would, of course, break the circuit and extinguish all the lamps.

A short-circuit of the voltmeter by means of the wire b_1 would not only affect the lamps in this house but in the whole neighborhood. It would send a very strong current across the conductors b, b_1, b, and either melt these wires or the safety-fuse which may be situated there. A fuse consists of a strip of metal through which an ordinary current will pass unimpeded,

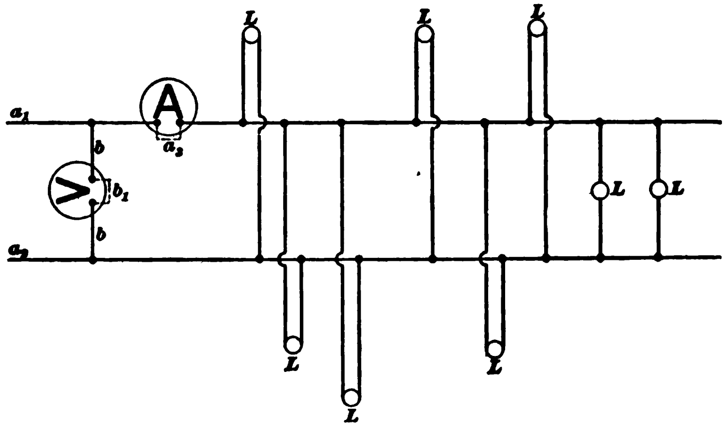


FIG. 27.

but which will heat and melt if the strength of the current goes beyond certain determined limits; it will, therefore, break the circuit and prevent any serious damage to the rest of the apparatus. Disconnecting one of the wires leading to the voltmeter, while in circuit, will have no other effect than simply removing the instrument from the circuit.

INFLUENCE OF RESISTANCE ON E. M. F. AND CURRENT.

40. After the functions of the voltmeter, ammeter, and rheostat have been studied separately, it remains to be seen how these instruments work in conjunction with one another. The effect that the rheostat has on the various parts of a circuit is a subject that is not clearly understood by beginners, and therefore requires some explanation, particularly as the rheostat plays such an important part in electrotherapeutics. The question to be answered is: Does the rheostat affect the current-strength only, or does it also affect the pressure at the battery terminals?

If this question were to be answered off-hand, it would seem, as a matter of course, that any resistance the rheostat might insert in the circuit would merely increase the total resistance of the latter, and therefore diminish the current-strength. A closer study of the condition will show that this answer is not quite correct, but that an increase of the resistance does in fact increase the available E. M. F. at the battery terminals. Of course, this does not mean that it increases the total E. M. F. generated by the battery; on the contrary, this E. M. F. remains practically constant, so long as we deal with voltaic batteries and not with dynamos or other generators.

41. Some practical examples, illustrated by means of Figs. 28, 29, 30, 31, and 32 will make the reasons for this perfectly clear.

Let the battery *B*, Fig. 28, consist of 10 cells, each of an E. M. F. of 1.2 volts and an internal resistance of .5 ohm. The

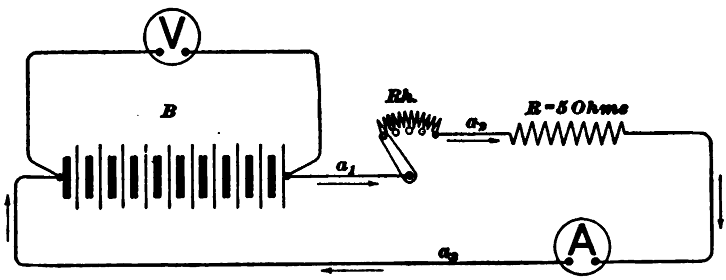


FIG. 28.

total E. M. F. of all the cells in series will therefore be $10 \times 1.2 = 12$ volts, and the total internal resistance $10 \times .5 = 5$ ohms.

In the same figure, *R* is an external resistance of 5 ohms, and *Rh.* a rheostat, which, by means of the conductors a_1 and a_2, connects, respectively, with the battery and the resistance *R*;

the conductor a_3 returns the current from the latter to the battery. A voltmeter and a milliammeter complete the arrangement.

It is the purpose, by means of this combination, to send a current from the battery B through the external resistance R, which latter may, for instance, be the resistance existing in a cautery loop applied to the human body for some local treatment. The number of amperes that will flow through this external resistance is to be controlled by means of the rheostat.

42. When no resistance is inserted by the rheostat, and the only resistances in circuit are those of the battery and the cautery, the conditions will be those represented in Fig. 29. Here we find the whole circuit of Fig. 28 extended along a horizontal line $a\,h$, representing zero potential, and the parts marked off in the same order as in the former figure. It is supposed that the point h connects directly with the point a, and that the various

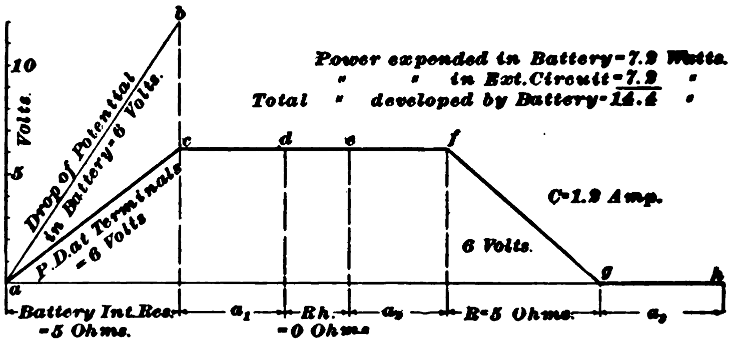


FIG. 29.

divisions marked with the letters a_1, $Rh.$, a_2, etc. correspond to the parts marked with similar letters in Fig. 28. It is also supposed that the conductors a_1, a_2, and a_3 are of such ample cross-sectional areas that the drop of potential taking place in them may be left out of consideration.

Beginning, then, with Fig. 29, we find, as the only resistances in circuit are the 5 ohms of the battery and the 5 ohms external resistance, that the strength of the current will be

$C = \frac{E}{R} = \frac{12}{5+5} = 1.2$ amperes. At the left end of the figure the line $a\,b$ indicates a rise of potential of 12 volts, which would take place if the battery were devoid of internal resistance. But a current of 1.2 amperes having to pass through its resistance of 5 ohms, the current suffers a loss in potential of $C \times R = 5 \times 1.2 = 6$ volts. The potential difference at the terminals of the battery will therefore be $12 - 6 = 6$ volts only, as represented by the line $a\,c$, and this is the pressure that will have to carry the current through the rest of the circuit. No resistance being inserted by the rheostat, and the resistances of the conductors a_1 and a_2 being left out of consideration, the potential of the current will remain unaltered while passing through them, and the lines $c\,d$, $d\,e$, and $e\,f$, representing the potential of these parts, will be lines parallel with the zero-line $a\,h$. At f the current enters the external resistance R of 5 ohms, and here suffers a loss of pressure amounting to $C \times R = 1.2 \times 5 = 6$ volts. This meams that the whole available pressure of the battery has been consumed in the resistance R, and that the current now, through the conductor a_3, again enters the battery at zero potential.

43. It was shown in *Direct Currents* that a battery gives a maximum power to an external circuit, when the resistance of said circuit is the same as that of the battery. As this corresponds with the conditions found in Fig. 29, we shall expect to here find a maximum power spent in the resistance R. The power expended on the various parts of the circuit is found by multiplying the loss of potential that the current suffers in passing through them by the strength of the current in amperes. The total power developed by the battery is $E \times C = 12 \times 1.2 = 14.4$ watts. That part of the total power which is spent in the battery itself, we find by multiplying the drop of potential in it by the current, or $6 \times 1.2 = 7.2$ watts. The external resistance R being equal to that of the battery, the drop will be the same, and therefore, also, the power consumed. We see, then, that, of the total power of 14.4 watts, 7.2 watts have been spent, respectively, in the battery and in the external circuit.

If the battery had been short-circuited, the total power developed would have been greater, but of course none of it would have been available outside of the battery. The current C that would circulate through the latter, in this instance, would have a strength of $\frac{E}{R} = \frac{12}{5} = 2.4$ amperes, and therefore a power of $E \times C = 12 \times 2.4 = 28.8$ watts.

44. In Fig. 30 the conditions are altered, for, by means of the rheostat, a resistance of 5 ohms has been inserted, making

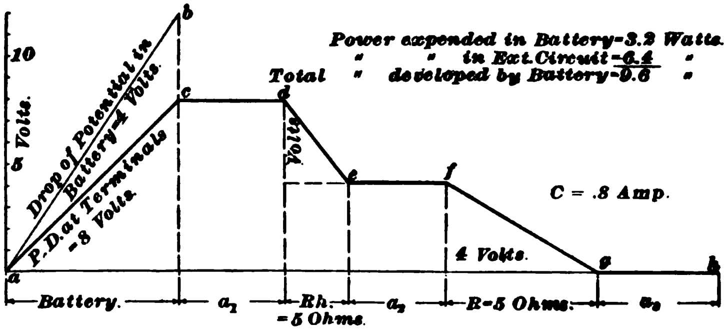


FIG. 30.

a total of $5 + 5 + 5 = 15$ ohms. The current-strength will now be $\frac{E}{R} = \frac{12}{15} = .8$ ampere, which is 33 per cent. less than that of the circuit shown in Fig. 29.

The strength of the current having decreased, it follows as a consequence that the loss of potential in the various parts of the circuit must also decrease, as these losses are products of current and resistance.

When we now calculate the loss of potential in the battery, it is found to be $C \times R = .8 \times 5 = 4$ volts, or 2 volts less than in Fig. 29; consequently the available E. M. F. at the terminals of the battery, or $12 - 4 = 8$ volts, must be larger than that previously at our disposal. Following the distribution of these 8 volts over the remainder of the circuit, we find, as before, that the current, while flowing through the conductor cd, suffers no loss of potential, but that, on passing through the 5 ohms resistance of the rheostat, the pressure at once falls from 8 to 4 volts, which pressure remains throughout the conductor ef; after leaving the latter the current again suffers a loss of 4 volts, caused by the 5 ohms resistance of the external resistance R.

Comparing the two examples, illustrated by means of Figs. 29 and 30, it is seen that the insertion of the rheostat resistance of 5 ohms has the effect of raising the available E. M. F. at the battery terminals from 6 to 8 volts, but that notwithstanding this increase the current-strength decreased from 1.2 amperes to .8 ampere. If the resistance and E. M. F. had increased in the same proportion, the current-strength would have remained the same; in this instance the exterior

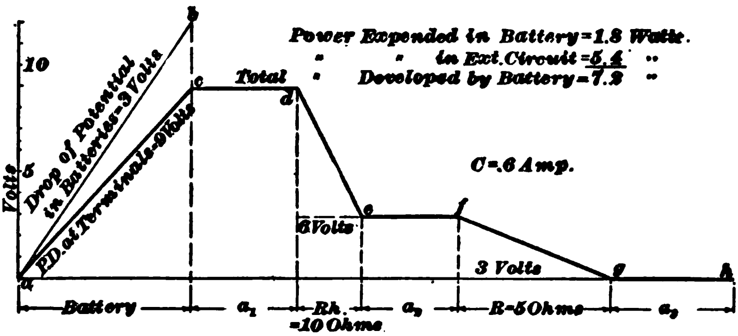


FIG 31.

resistance is increased by 100 per cent. and the terminal E. M. F. by 33 per cent. only; the latter, therefore, did not keep step with the former, with the result that the current decreased. Had the terminal E. M. F. remained the same as before, the current would have been .6 ampere only; but, being increased by 33 per cent., the amperage rose from .6 to .8 ampere.

We come, then, to the conclusion that increasing the resistance in the external circuit of a battery does not decrease the current in the same proportion, because the available E. M. F. increases simultaneously, though not in the same ratio.

45. In Fig. 31, the resistance of the rheostat is increased to 10 ohms and the current has now decreased to $\frac{E}{R} = \frac{12}{20} = .6$

ampere, while the drop of potential in the battery is 3 volts only, and therefore the available E. M. F. = 12 — 3 = 9 volts. The other losses in the circuit can easily be seen by the data given in the figure.

46. As a final example of the influence exerted by the rheostat, we will consider the circuit illustrated by means of Fig. 32. Here the rheostat has increased its resistance to 30 ohms, making a total resistance for the whole circuit of 40 ohms. The current has now fallen to $\frac{E}{R} = \frac{12}{40} = .3$ ampere. At the same time the loss of potential suffered in the battery has decreased to 1.5 volts, which leaves an available

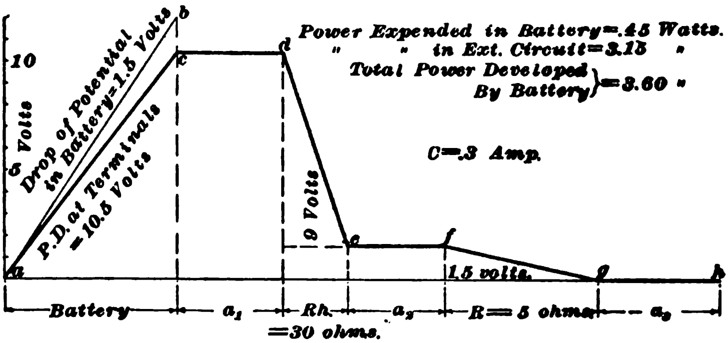


FIG. 32.

pressure at the terminals of 12 — 1.5 = 10.5 volts. In the rheostat the loss is now 9 volts, while in the permanent resistance R it is 1.5 volts only. This last example brings out more clearly another feature, that an increase of the resistance in the circuit external to the battery will bring the available pressure at the terminals nearer the total E. M. F. of the battery, and at the same time the current will decrease in strength. Finally, the resistance will be so great that the current practically stops altogether; the circuit is then in the same condition as when open, and the pressure at the battery terminals will be identical with the total E. M. F.

47. Data relating to the power spent in the external circuit are given in each figure. It is at once seen that the power has reached its maximum value when the conditions are as shown by Fig. 29; that is, when the external resistance is equal to that of the battery. An increase or decrease of the resistance in the external circuit will have the same result—that of decreasing the available power. Simultaneously with the decrease of the current the number of watts spent outside of the battery will also decrease until, in Fig. 32, the power spent has the value of 3.15 watts only.

48. The condition that must prevail if maximum power is to be given an external circuit may also be expressed in another way, by saying that, if a voltmeter, connected with a battery as in Fig. 28, indicates a pressure of one-half of the total E. M. F. of the battery, maximum work is being done in the external circuit. This of course does not mean that the resistance, outside of the battery, may be increased by means of a rheostat until the desired value of the terminal pressure is reached. It is true that in this case also maximum power is given to the circuit, but the resistance R receives only a small fraction of it, the greater part being uselessly wasted in the rheostat, where the electrical energy is changed into mechanical energy in the form of heat. It is therefore clear that, if a device external to the battery is to receive a maximum power from the battery, this device itself must constitute the external resistance.

CURRENT-SELECTORS AND POLE-CHANGERS.

49. Advantages of Current-Selectors and Pole-Changers.—There remains to mention a little device that is very useful to the physician when applying the electric current, and that is the double switch shown in Figs. 33 and 34. In construction it is identically the same in both illustrations, but its connections with the circuit are different and the results obtained are, therefore, also different. When the operator uses an apparatus called a *switchboard*, which is described further on, he has often the choice of two different kinds of current, such as the galvanic and the faradic. It is then of advantage to have the switchboard so arranged that either of these current varieties can be sent through the main binding-posts without having to make any change in the connections. This is accomplished by means of the **current-selector.** At other times it may be of advantage to change the polarity of the electrodes without having to disconnect them. Arranged for this purpose, the double switch performs the function of a **pole-changer.** Ordinarily these are used in combination, so that it is possible not alone to choose the current variety with which the electrodes are to be supplied, but also to change their polarity.

50. Current-Selectors.—A device of this kind is represented by the diagram Fig. 33. *B* is a voltaic battery that,

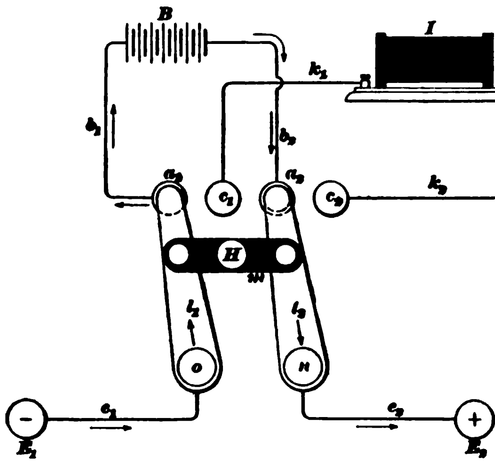


FIG. 33.

through the two conductors b_1, b_2, is connected to the buttons a_1, a_2. *I* is a faradic coil that connects with the buttons c_1, c_2 by means of conductors k_1, k_2. The levers l_1, l_2, compelled to move in unison by the cross-piece *m* (which is made of insulating material), may connect either with a_1, a_2 or c_1 c_2, respectively. They swing around the posts *n* and *o* and may be moved by means of the handle *H*. The main binding-posts E_1, E_2 connect with the levers through the conductors e_1, e_2. In the position that the levers at present occupy, a current is sent from the battery *B* to the posts E_1, E_2, and the faradic coil *I* is cut out. On moving the levers into a position so as to connect with buttons c_1, c_2, the faradic coil is included and the battery B excluded from the circuit and a faradic current will pass through the same posts E_1, E_2.

51. Pole-Changers.—When the double switch is used as a pole-changer, its connections are those shown in Fig. 34. Here the positive wire b_1 of the battery B is connected both to buttons a_1, d_2, thus making both positive. Similarly, the negative conductor c_1 is connected with buttons d_1, a_2, making both

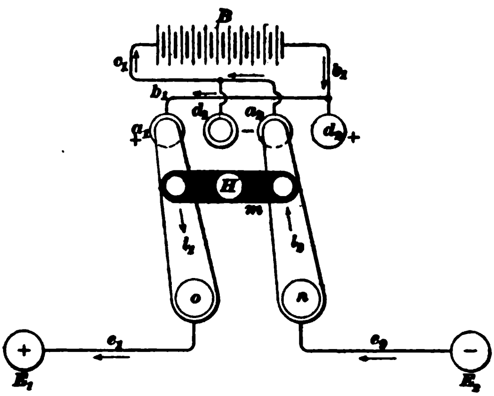


FIG. 34.

negative. Otherwise the connections are the same as in Fig. 33. When making contact with the buttons a_1, a_2 as shown, electrode E_1 will be positive and E_2 negative. On pushing the levers to the right, the polarity of the electrodes will be reversed and E_1 will now be negative and E_2 positive.

SWITCHBOARDS.

52. Function of Switchboards. — Under the term **Switchboards** is ordinarily understood a board having a collection of switches for making or breaking various circuits. It should also include means for ascertaining the amperage and voltage of the current that may flow in the circuit. In electrotherapeutics, a switchboard means the same with this addition, that it may also include means for producing one of the current varieties, such as a faradic coil, with the necessary cells or a collection of voltaic cells for producing the direct current.

53. A Typical Switchboard.—It would complicate matters too much to go into a detailed description of any of

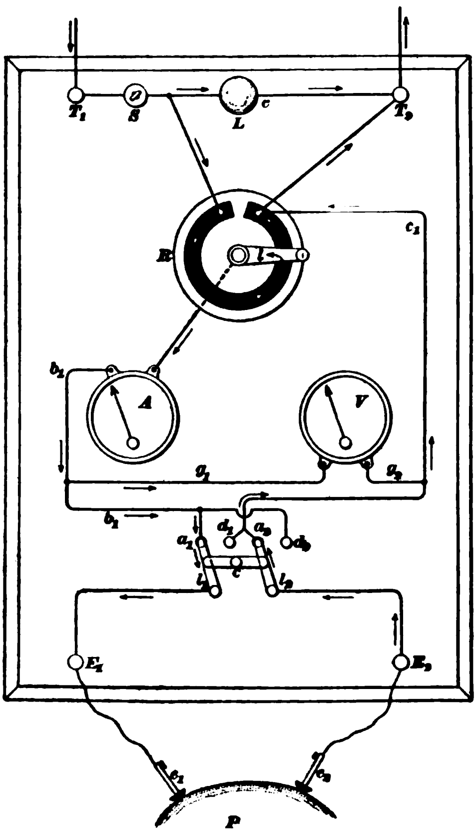


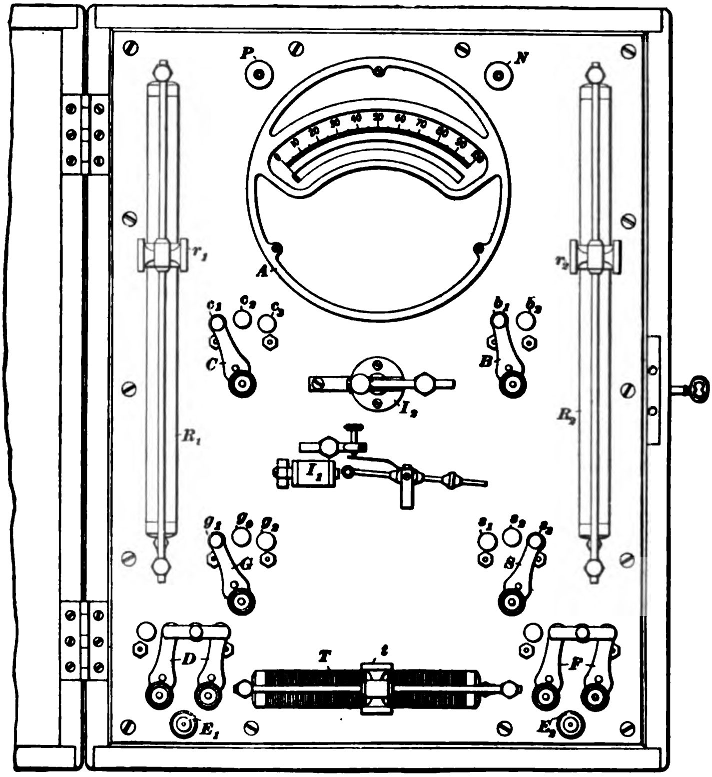
FIG. 35.

the switchboards, therefore we must limit ourselves to a general description of same. The diagram, Fig. 35, will serve this purpose. It represents a switchboard that will control and register the current delivered from a direct-current lighting circuit. T_1, T_2 are the binding-posts that connect the board with the general circuit of 110 volts. The current passes directly from one post to the other through the cut-out switch S and incandescent lamp L. Arranged in shunt with the latter is the rheostat R of about 10,000 ohms resistance. The current flowing between the posts T_1, T_2 will, therefore, divide itself between these two parallel circuits, the greater part flowing through the lamp L of about 220 ohms resistance and the smaller part flowing through the rheostat. From the latter, the current flows along the lever l to the ammeter A and from here through the conductor b_1 to the pole-changer c, which is arranged in the same manner as shown in Fig. 34 with regard to the binding-posts E_1, E_2. After flowing through the electrode e_1, patient P, and electrode e_2, the current again returns through the pole-changer, to the rheostat and other binding-post T_2, to the external circuit.

The conductors g_1, g_2 connect the voltmeter V across the conductors b_1, c_1 and will therefore indicate the electric pressure to which the patient's circuit is subjected.

For simplicity's sake we have in this instance supposed that the current was supplied from a lighting circuit. The supply may also come from a battery of voltaic cells, in which case a cell-selector and rheostat may be inserted in the circuit, or simply a rheostat. In either case the lamp L would be omitted.

54. Switchboard for Galvanic and Faradic Currents.—As an example of an efficient switchboard by means of which either the galvanic or faradic current may be supplied, we give that illustrated in Fig 36. It is made in the shape of a box, to enable the operator to carry it around from one part of the building to another, as may be necessary in a hospital, and also makes it possible to lock it and thus prevent its being handled by any one that is not familiar with its construction. The front is a panel of polished slate, to which all the various devices are directly fastened. Behind this, and firmly supported by it, is the faradic coil; likewise the dry cells for supplying the current for its primary coil. There are also four resistance-coils that act as volt selectors in the same manner as the lamps shown in Fig. 15, when the direct current from a commercial lighting circuit is used. Everything not absolutely necessary for the selection and variation of the current is put out of the way, which makes it possible for the operator to handle the board with the least amount of confusion.



Galvano-Faradic Switchboard.

FIG. 36.

55. Importance of a Good Meter.—In using the galvanic current, everything centers around the milliammeter. The latter should be above suspicion, as regards its correct indication of the current-strength, and should not be liable to change or deteriorate in such a manner as to affect its future indications. In many delicate operations the current dosage may be only a few milliamperes, and it is here important that the readings of the meter should be absolutely reliable. It should also preferably be dead-beat, in order that sudden variations may be made in the current-strength without causing the pointer to fly violently all over the scale with the possibility of striking the stops at the end of the scale and thus cause an injury to the meter.

56. Method of Applying the Direct Current.—When it is desired to use the direct current from the commercial lighting circuit, then conductors connected with the latter are attached to the two binding-posts *P*, *N*—*P* being positive and *N* negative. The switch *B* serves the purpose of making or breaking the connection between the lighting circuit and the various circuits of the board. In the position indicated, the current is cut off. The binding posts E_1, E_2 receive the conducting cords of the electrodes with which the patient is to be treated. *D* is the current-selector that must be moved to the left in order to connect the posts E_1, E_2 with the galvanic circuit.

The board is intended to be used with a 110-volt circuit. As this voltage is inconveniently large to use directly, the current is sent through four resistance-coils connected in series. Three of these coils are connected with the buttons c_1, c_2, c_3 of the volt selector *C*. This makes it possible to supply an electric pressure to the binding-posts E_1, E_2, of either 30, 60, or 90 volts. The fourth coil remains always in series with the patient. Whatever pressure is selected, the pressure at the posts E_1, E_2 may be reduced to zero by pushing the sliding contact r_1 of rheostat R_1 down to the lower end of the same. The desired current-strength may then be obtained by raising r_1 until the meter *A* registers the desired number of milliamperes.

The pole-changer *F* will give the operator the desired polarity at the posts E_1, E_2.

57. Method of Applying the Faradic Current. When the faradic coil is to be inserted in the patient's circuit, the current-selector *D* is moved to the right. The current is supplied by the dry cells back of the board, as soon as the switch G is moved from its contact with the central button g_0 either to the left or right. If pushed to the right, the rapid interrupter I_2 is set in action; if to the left, the slow interrupter I_1. The switch S determines the active length of the secondary coil, as the buttons s_1, s_2, s_3 connect respectively with the divisions containing 300, 800, and 1,500 yards of wire. The rheostat T, with contact-spring t, regulates the current from the cells through the primary faradic coil, and the rheostat R_2 with contact r_2 that of its secondary circuit, while the pole-changer F, also in this circuit, may effect a change of polarity of the posts E_1, E_2. Both rheostats R_1, R_2 are in shunt with their respective circuits.

ELECTRODES.

58. Function of Electrodes.—When electricity is therapeutically applied, the aim is to send an electric current through a given part of the human body. When thus applied the latter constitutes necessarily one part of an electric circuit while the current source constitutes the other part. So far, we have considered solely that part which contains the source with the necessary means for regulation and registration; the other part, the human body, will be considered elsewhere. There is yet a third element to be considered, the junction between these two parts. Evidently there are no means for making that intimate electric connection between them as in other parts of the circuit, and some means must be found to make a temporary connection that will, in the main, fulfil the requirement of providing a free path for the current from one part of the circuit to the other. As the body itself does not offer a metallic surface with which to connect, a substitute is found in some fluids of fairly high conductivity. This fluid is interposed and confined between the metallic terminals of the electric source and the tissues of the human body. Being a fluid, it will more or less penetrate the external layer of the various tissues and thus provide a more intimate contact and extended surface area. Where the tissues themselves provide the fluid, such as mucous membranes, a simple metallic contact surface is usually sufficient. Devices that serve this purpose of acting as an intermediary between an electric source and the human body in supplying the necessary contact-surfaces and possessing the required conductive properties are called **electrodes.**

Ordinarily the receptacle for the intervening liquid is a piece of sponge, a pad of gauze, cotton, felt, or perhaps clay or gelatine. Or it may, in the case of the hydro-electric bath, be contained in a full-sized bath-tub, or smaller tubs, when it is a question of simply treating part of the body.

59. Classification of Electrodes.—It is not the intention, at this place, to go into a detailed description of the numerous electrodes used in electrotherapeutics. They will suffer numerous variations in form to best adapt them for the immediate purpose in view, and these variations will be described under the special treatments considered in other parts of this course. The present aim is rather to call attention to the main requirements of a good electrode and the reasons for its deterioration or inefficient function.

Electrodes used for applying the current from static machines will not be considered here, because the electric pressure available in those cases is so high that in most cases no immediate contact between electrode and patient is required. It is here mostly a question of applying the galvanic, faradic, and sinusoidal currents. The electrodes utilized for this purpose may be divided in two main classes: (1) those having a metal terminal that supplies the current directly to the tissues, and (2) those that have a fluid as an intermediary. These two classes are otherwise known as *bare* and *covered* electrodes.

1. *Metal Electrodes.*—The main requirement regarding these electrodes is that they shall not be acted on chemically by the solutions that are electrolytically separated from the tissues while traversed by an electric current. Small electrodes, such as are used in the ears and similar places, are generally gold-plated, while larger electrodes have a coating of nickel. When it is required that the electrode shall cover a very extended area, sheets or strips of tin are used.

Most electrodes consist of a metal rod, which at one end terminates in that part that is to be brought in contact with the body and at the other end is provided with a binding-post to receive the conducting-cords from the battery. The metal rod is covered with some insulating material such as wood or hard rubber to prevent communication between it and the operators hand.

It has already been remarked that the positive electrode is of acid reaction and the negative of alkaline. As metals, such as brass and copper, are affected by acids, the active electrode should always be made negative, unless special reasons require that it be made positive. Being negative, it will, notwithstanding the greater current-density through it, be little affected by any chemical action; while on the other hand, the positive indifferent electrode is of so much larger area that the acid effects are little noticeable.

2. *Covered Electrodes.*—These are of many varieties. They consist mostly of a metallic frame, or skeleton, that acts as a support for some fibrous material with which it is covered. This covering serves as the receptacle, or retainer, for the fluid which fills the function of an intermediary between the metallic framework and the tissues of the body. The metal mostly used for support is perforated brass. As it oxidizes rather freely, it is difficult to keep its surface in as good condition as it should be, and perforated aluminum sheets of about No. 24 B. and S. gage would therefore be greatly preferable, as less liable to oxidation, much lighter, and of a more bright and cleanly appearance. It should be remembered that the prime function of this metal skeleton is not that of supporting the surrounding pad, but that of evenly distributing the electric current to the same. For this reason, it is of paramount importance that this metal plate has a good conducting surface, free from any metallic oxids or other impurities, which will impair its conducting properties. In some cases, the resistance that these oxids interpose in the circuit may be so great as to stop the current altogether. Carbon is also used as the conducting support, either in the form of a small ball that is surrounded by a wad of cotton or in the shape of disks or plates. As carbon does not oxidize, it has, in this respect, advantages over the metal plates.

60. Distinction is also made between an *active* and *indifferent*, or *dispersing*, electrode. An **active electrode** is the one that is applied to that part of the body where the effect of the electric current is desired.

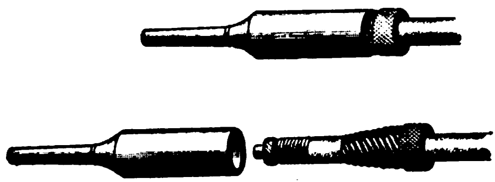
The **indifferent electrode** serves simply the purpose of completing the electric circuit, and derives its name from the fact that it ordinarily is indifferent where it is placed. It is usually of an area much larger than the active electrode, because it is desirable to disperse its action as much as possible and thereby prevent any effects on places where it is not desirable.

61. We have already mentioned that an electrolytic action is carried on by the electrodes. The products resulting from this decomposition has often a very deleterious effect on that part of the skin that is covered by the electrodes and may leave eschars that are difficult to heal. For this reason it is sometimes advisable to use *non-polarizable* electrodes. These contain mostly a small chamber filled with a solution of sulfate of zinc. Between the interior of this chamber and the tissues to be acted on, is a cover of some porous material that allows intercommunication between them. The electrolytic products will therefore not remain near the skin, but will pass through the cover into the chamber and thereby be prevented from producing any harmful action on the tissues.

Regarding the antiseptic treatment to be given the covering of electrodes, full information will be found in subsequent sections. To maintain their electrical function at maximum efficiency, the metallic surfaces that adjoin the covering should be frequently rubbed with sapolio or bon ami, and in extreme cases with fine emery paper—in order to remove any oxids that may have accumulated on them.

CONDUCTING-CORDS.

62. Conducting-Cords connect the electrodes with the switchboard or any other current source. To insure a certain mobility to the electrodes, the conducting-cords are made of fine strands of copper wire that are covered with silk or cotton. The cords should have cord-tips at either end to facilitate their easy insertion both in the binding-posts of the switchboard and the electrodes. A universal cord-tip is shown in Fig. 37, where the upper figure shows the tip and cord assembled, while the lower figure illustrates how the tip may be taken apart in order to insert a new cord in the same. When cords are subjected to sharp bends, they may, in time, break without showing any exterior signs of such. Sometimes the cause of the irregular



Universal Cord-Tips.

FIG. 37.

action of the current from a faradic coil are looked for in vain, until finally the fault is found in one of the cords.

The cord-tips are supposed to be of such dimensions that they will fit any binding-posts. Though such conditions are greatly to be desired, they are not yet, by any means, attained, and the practitioner sometimes finds himself in possession of apparatus that will not receive his cord-tips until some subsequent tinkerings have been performed.

THE HYDRO-ELECTRIC BATH.

63. Characteristics of the Hydro-Electric Bath. When it is a question of giving the electric current an opportunity to act over extended areas of the human body, the **hydro-electric bath** is utilized either for the whole body or part of same. The bath may then, in one respect, be said to perform the function of an enlarged electrode; but in some other respects it differs. This is because the body is immersed and is surrounded by water from all sides. When an ordinary covered electrode is applied, the whole current must go through it, and it alone, before it can pass into the body, as the electrode is the only path by which the current can enter. By letting a certain quantity of water completely surround the body, the water itself will offer a by-path for the current. The adjacent layers of water may be said to be in shunt with the body, and as such will be subject to laws of an ordinary shunt. That is, it will conduct a part of the current, the strength of which will depend on the resistance of the shunt relative to that of the main conductor—the body. If the fluid is of a relatively high conductivity and the body of a lower one, it is obvious that most of the current will pass outside of the body and the desired results will not be obtained. It is possible though, by means of the electrodes through which the current is sent into the bath, to more or less counteract this dispersing effect of the water and to localize the action of the current on those places where it is desirable that it should act.

CONSTRUCTION OF THE BATH.

64. Material of Bath-Tub.—It is important that the tub should not be a conductor of electricity, otherwise the whole current will circulate around the water without entering it. Even a metal bath-tub covered with an insulating coating is to be avoided, as sooner or later some parts of the coating will wear or break off, and then the current will be able to make a short circuit through the metal wall. Oak or porcelain are the most suitable materials for its manufacture, the latter being the more cleanly of the two.

65. Importance of Insulation.—Insulation is an important point that needs careful attention—particularly if the current from the lighting circuits is to be utilized. In the latter case the water in the tub must not be directly connected with the waste- or water-pipe, as either of these communicates with the ground; the current would, in case of a short circuit on the main line be able to pass up through these pipes and subject the patient to a very strong current. Therefore the necessity of having the tub entirely disconnected both from the waste-pipe and from the water-supply pipes.

66. Insulation of the Bath-Tub.—Fig. 38 gives the general arrangement of a tub that is entirely separated from any ground connection; it is in sectional elevation and represents a tub made of oak partly filled with water. *A* is the tub itself, and *B* a back rest to prevent a direct contact with the anode *a*, which is here the head, or cervical, electrode; the cathode, or foot, electrode *b* is unprotected. The dimensions of the head-electrode may be 11 × 12 inches, and of the foot-electrode about 9 × 14 inches. The stopper is marked *d* and is inserted in the upper part of the short outlet tube *e*; consequently, there is no direct connection with the sewer-pipe *g*. The pipe *e* conducts the water into a shallow basin *f*, from which it flows

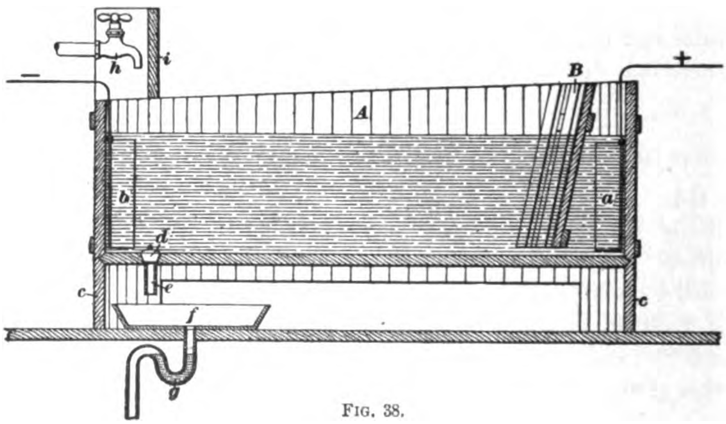


FIG. 38.

into the pipe *g*. Around the supply pipe *h* is built some kind of a guard *i*, to prevent a direct contact with the tube *h* on the part of the patient; otherwise, he might, under certain conditions, be exposed to a short circuit. To give room and access to the basin *f* and also to give free circulation of air under the tub, the latter is supported by legs *c*, *c*.

When the current is supplied to the bath from a local current source, as for instance, an independent dynamo, a voltaic battery, a faradic coil, a sinusoidal apparatus, or a transformer, then these precautions are unnecessary and an ordinary enamelled or porcelain bath-tub provided with the customary plumbing connections, may be utilized.

MONOPOLAR AND BIPOLAR BATHS.

67. Bipolar Bath.—A bath may be *monopolar*, *bipolar*, or *multipolar*. So far, the baths considered have been of the **bipolar order,** and to this class the multipolar baths may also be said to belong, as a multiplication of poles simply means a subdividing of the anode and cathode.

68. Monopolar Bath.—By **monopolar bath** is not meant a bath with one active pole only, but rather a bath that contains only one electrode submerged in the water while the other is exterior to same. The bath-water is therefore of one polarity, either positive or negative, and may be considered as an electrode that completely envelops the body and thus provides a very large surface contact.

69. Difference Between Monopolar and Bipolar Baths.—There is quite a difference between a monopolar and a bipolar bath. A current is passing through the latter, of which the body receives a certain portion, depending on its position and size, some parts receiving more than others; how much, as has been shown, it is not always easy to tell.

In the monopolar bath, the conditions are entirely changed. Here the exterior electrode, for instance, the anode, is placed in contact with the body at any desirable point, and at this point the current is compelled to enter—here only, and what is more, the whole current. There is, then, no longer any uncertainty of where the current acts and in what strength. In leaving the body again, the current is diffused over a very large area; in fact, over the whole submerged part of the body.

The monopolar bath may therefore localize the action of the current to one particular spot, if desirable, while the bipolar bath gives a general distribution of electricity through the whole body. The exterior pole, in a monopolar bath, may consist of a metal rod, covered with wash-leather and placed across the widest part of the bath. This rod is connected, by a well-insulated wire, to one of the terminals of the electric source; when the patient grasps the rod in his hands, the current passes through his arms and trunk to the water.

70. Paddle Electrode.—If it is desirable to localize the action of the current to one particular spot, a **paddle electrode** is used. This consists of a metal electrode whose dimensions are about 5 in. × 7 in., and which is provided with a long handle of insulating material. The operator can, by means of this electrode, concentrate the action of the current on any desirable part of the body, either by holding the electrode stationary against the part in question, or by imparting to the electrode a circulating motion, if it is desirable to affect a larger area.

71. Other Electrodes.—In the **multipolar bath** there is, besides the electrodes at the head and the foot of the bath, also a **lumbar electrode,** usually 6 in. × 10 in. By means of these three electrodes, various combinations may be made. For instance, the lumbar may work in conjunction with the head, or as it is usually called, the cervical electrode, and the foot-electrode. Or, the cervical may be placed opposite the lumbar electrode, and both act as lateral electrodes. If the foot-electrode is removed and the lateral electrodes are of opposite polarity, the current will travel across the bath only, and act on the special organs situated in its path.

A further variation may be made by covering the lumbar electrode with a light wooden framework and utilizing it as a *gluteal electrode.* By letting the patient sit on this and use it in conjunction with the cervical and foot-terminals, or with the latter alone, a further localization of the current may be accomplished.

It should be remembered that the quantity of current which the body will receive, also depends on its proximity to the electrodes, so that this provides a further means for giving a local as well as a general application of the electric current.

72. Stationary and Movable Electrodes.—The various electrodes used in a multipolar bath may be either *stationary* or *movable.* In the former instance, the walls of the bath are usually perforated and the insulated wires passed through these openings. The conducting wires lead to a common switchboard, where, by means of plugs, any electrode may be thrown in or out of action. This arrangement of stationary electrodes has certain advantages from the fact that the electrodes are always ready for action and need no additional handling. At the same time, there are certain drawbacks inherent in the system. For one thing, the arrangement is less flexible than with movable electrodes, unless their number is increased; then again, the perforation of the sides of the bath leads sooner or later to a leakage. But the greatest disadvantage results from the numerous electrodes constantly situated in the bath, some of which at times are idle and, as such, cause complications that it is difficult to avoid.

The reason for this is that those electrodes that are idle are at the same time parallel with the submerged body and constitute a shunt to the same. As such they will divert part of the current. In other words, the electrodes serve to short-circuit the other electrodes, thus preventing the body from receiving the current intended for it.

For these reasons it is preferable to have removable electrodes and to have them supported by means of metal strips or wires that pass over the edge of the tub instead of through the walls.

73. Switchboard for the Hydro-Electric Bath.—To facilitate the changes in polarity of the several electrodes, the switchboard shown in Fig. 39 may be used to advantage. Plate I is for the head, Plates II and III for the left and right sides, respectively, and Plate IV for the foot-electrode. When the plugs are placed, as shown in the illustration, it would mean that the head-electrode is of one polarity, and the left side, right side, and foot of another polarity. By taking out all the plugs and inserting one in

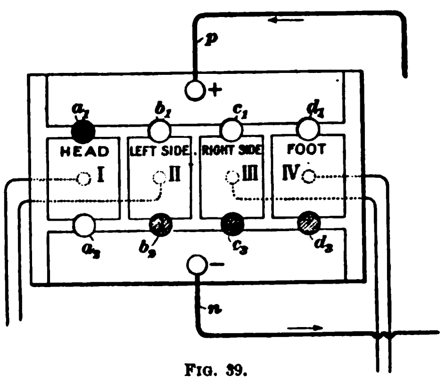


FIG. 39.

hole b_1 and another in c_2, the whole current would go from the left side to the right. In the same manner, other current paths may be effected by arranging the plugs in different ways and thus localizing or accentuating the action of the current on certain parts.

74. Construction of the Electrodes.—The electrodes should be made of bright metal that does not oxidize too freely; for this purpose aluminum sheets, of, say, No. 24 B. & S. gauge seem the most serviceable. They can be easily cut to the desired dimensions, do not oxidize, and look clean and bright. If necessary, they may be covered with a light lattice frame, which can be removed when the electrodes are to be cleaned.

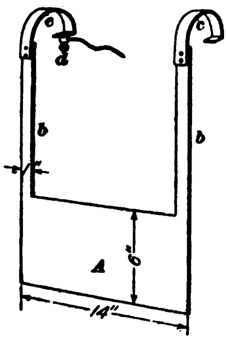


FIG. 40.

The form of the electrode may be as shown in Fig. 40, which represents a lumbar electrode of the dimensions given. A is the electrode proper, b, b the strips from which it is suspended and which are riveted to the hooks c, c. The latter rests on the edge of the tub and may be slid along the same into any desired position. At d is a binding-post for connection with the conducting-cord.

75. Current-Density.—By **current-density** is meant the current-strength per unit of cross-sectional area of a conductor; in the present case, the square foot may be taken as the unit of area. We see, then, that the density must vary directly with the current-strength and inversely with the area of the transverse section. That is, if the strength of the current is constant, an increase in sectional area of the conductor will decrease the density of the current per unit area.

If D stands for density of current, C for current-strength, and A for the sectional area, then $D = \frac{C}{A}$. Let, for instance, the current-strength through a body be .266 ampere and its sectional area 3 square feet. The density through same then is $D = \frac{C}{A} = \frac{.266}{3} = .089$ ampere per square foot.

76. While speaking of density, it may here be of interest to mention a peculiar variety of electric bath. It has been devised for the purpose of avoiding the loss of current caused by the latter passing through the water in parallel with the body. A diaphragm of rubber is placed across the bath enclosing the human body, thus dividing the bath in two. The current will then, at the point where the diaphragm is situated, pass wholly through the body, because it is unable to pass through the diaphragm. It is true that by this arrangement the whole current will go through that part of the body inserted in the diaphragm and that it here will be of maximum density. But as a consequence the density through other parts of the body will be determined by the tolerance of that in the diaphragm, and the rest of the body will therefore necessarily be traversed by a current of low density. Very similar results may be obtained by arrangements such as the monopolar bath.

VARIETIES OF CURRENTS USED FOR HYDRO-ELECTRIC BATHS.

77. Direct and Alternating Currents.—The electric current in nearly all its varieties is used for hydro-electrical purposes. We have first the ordinary direct current, as furnished by a voltaic battery or by the lighting stations; then the pulsatory current, as delivered by some sinusoidal apparatus in which the alternating current can be changed into unidirectional. The faradic current from an induction-coil or the alternating current from a sinusoidal machine, or from a transformer fed from some lighting circuit, are also employed.

78. If the direct current is to be supplied by means of voltaic cells, it is of importance that the latter are of good size, so as to be of sufficient capacity and able to run for a long period without renewal. The method of selecting the proper number of cells and connecting them has already been explained. The current may be regulated by means of a rheostat, of a size large enough not to heat, or by means of a double-handed cell-selector. The rheostat should be able to regulate a current of 300 milliamperes without overheating, and both the rheostat and cell-selector should be so made that the current can be entirely shut off.

79. Measuring Instruments.—For proper regulation of the current-strength through the bath a milliammeter is necessary that will register up to 300 milliamperes. Sometimes a voltmeter is also convenient when it is a question of ascertaining the voltage of the battery or the separate cells. Some milliammeters are so made that, by the addition of a suitable resistance, it may be changed into a voltmeter.

80. Current From Lighting Circuits.—When the direct current is taken from the lighting circuit, the bath must, as has already been said, be well insulated. In addition to disconnecting the bath from the waste and supply pipes, it should be placed either on plates of vulcanized rubber or glass.

81. Current From Induction-Coils.—When the current from an induction-coil is used, the latter should be one that has an interrupter with a smooth action; its speed should be variable between wide limits, say between 1,000 and 4,000 interruptions per minute.

So-called bath coils, which simply consist of a primary coil, are also used for the electric bath. They depend for their action on self-induction alone, and belong, therefore, strictly in the class of the direct-interrupted current, as the latter does not change in direction. Its self-induction is high; the make-current is therefore very weak, and the break-current predominates to such an extent that it is really the only active one. Its regulation is accomplished by subdividing the coil and throwing part of it out of action, if the current-strength is to be reduced.

82. Current From Alternators.—The alternating current from the lighting circuits has been used quite extensively in operating transformers intended for the supply of a sinusoidal current. Some practitioners prefer to use the supply current for the operation of a motor and let the latter drive a sinusoidal machine. This arrangement gives an opportunity for regulating the voltage as well as the frequency of the alternations.

DYNAMOS AND MOTORS.

DYNAMOS.

FUNDAMENTAL PRINCIPLES.

83. Conversion of Mechanical Into Electrical Energy.—In the voltaic cell we have seen a source of electromotive force, in which chemical energy was changed into electrical energy. Under certain conditions this source was found satisfactory, but where the supply was to be continuous and the output in watts large, it would, in addition to being inconvenient, also be very expensive. Under these conditions the advantage lies with a source of electromotive force in which mechanical energy is changed into electrical energy.

In *Magnetism and Electromagnetism*, when treating of electromagnetic induction, we observed that a wire moving across a magnetic field, or vice versa, had an E. M. F. created in it. This was taken advantage of in the induction-coil by changing a low E. M. F. into a high one, and was also utilized in the sinusoidal apparatus for the production of an E. M. F. The latter machine properly belongs in the class where mechanical energy is changed into electrical; but, as the power consumed is so small, and its field of usefulness limited mostly to that of the induction-coil, it was treated in conjunction with the latter.

Fig. 33, *Magnetism and Electromagnetism*, showed the effect of moving a conductor across a magnetic field. It would naturally suggest the idea that a machine built on that principle could be advantageously used for generating an E. M. F. on a larger scale by adding more conductors and moving them at high speed.

Since it is, of course, impossible to constantly supply new conductors, provision must be made for returning the conductors to their original positions, and let them repeat their motion through the magnetic field without interfering with the action of the machine.

These conditions are complied with if the conductors are arranged along the curved surface of a cylinder or radially along the sides of a disk, and if either of these are set in rotation in a magnetic field. We will consider the cylindrical form only, as shown in Fig. 41.

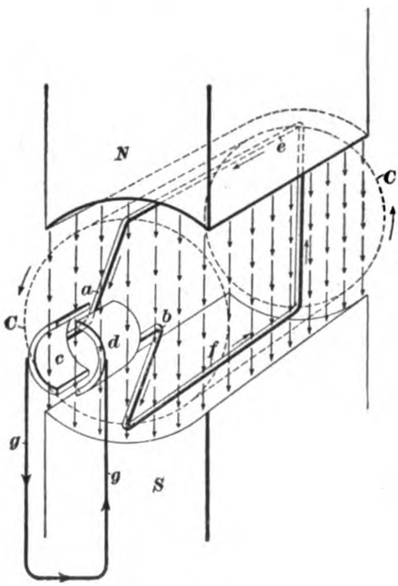


Fig. 41.

Here we have a conductor *a e f b* bent along the surface of a cylinder, shown in dotted lines, and rotating with it in the direction shown by the arrows. The ends of the conductor are joined to the segments *c*, *d*. *N* and *S* are the poles of the magnet, and, as *N* is the north pole, the lines of force will pass in the directions indicated by the arrows on the dotted lines. From the rule given in Art. 54, *Magnetism and Electromagnetism*, we find that the direction of the E. M. F. induced in the lower part *f* of the conductor is as indicated by the arrow, and we also find that the induced E. M. F. in the upper part of the conductor *e* acts in the opposite direction. The result is that the two electromotive forces act in the same direction, so far as the conductor is concerned; that, therefore, the total E. M. F. will be a sum of two; and that there is a tendency to start a current in the direction of this E. M. F. If, now, a conductor *g* is held, as indicated, against the segments *c*, *d*, a current will flow through the conductor as indicated.

84. Coil and Commutator.—To increase the action of the machine, wind the conductor several times around the cylinder, each convolution adding to the E. M. F.; it constitutes then what is called a **coil.** It is also evident that it would be a waste of space to let the rest of the cylinder lay idle; that, in fact, it would be natural to provide the whole circumference with conductors, and that each would be connected with segments similar to *c*, *d*, but that the latter would have to be made correspondingly narrower, so as to allow space for the rest. These segments would all be insulated from one another, and form a cylinder called **a commutator,** so named because it commutes currents running in opposite directions into currents running in the same direction, and under certain conditions combines these currents into one uniform current.

Instead of making contact with the commutator by means of a conductor *g*, it is customary to provide two broad plates, either of carbon or of laminated copper, called **brushes,** and let the terminals of the machine be connected with the supports of these brushes.

85. The machine described has one great drawback; there is only one conductor at a time in communication with the brushes. Any electromotive forces that may be generated in the other conductors are useless; they cannot start currents, because their segments are insulated from one another, like *c*, *d*, and, therefore, their circuits are open. Even could currents flow, they would be unable to reach the brushes, and would simply waste their energy in their respective circuits. To eliminate this great fault, all the conductors or coils are connected with one another, constituting one large coil.

86. Armature.—As yet, no mention has been made of the cylinder *C*, indicated by dotted lines. It could be made of any material, simply acting as a support for the conductors, but it is always made of laminated iron. It is made of iron, because iron is a good magnetic conductor, and thus, practically, is a continuation of the magnetic pole-pieces *N*, *S*; and it is laminated in order to avoid the starting of Foucault's current.

This combination of the conductors and an iron cylinder or drum is called an **armature.**

It is not necessary that the conductors be supported by a cylinder; they may also be wound around a ring, as shown in Fig. 42, and then constitute a **ring armature,** while the former is called a **drum armature.** The iron ring or drum is the **core.**

87. Ring Armature.—In Fig. 42, we see all the coils a_1, a_2, etc. connected with one another, constituting one coil; we

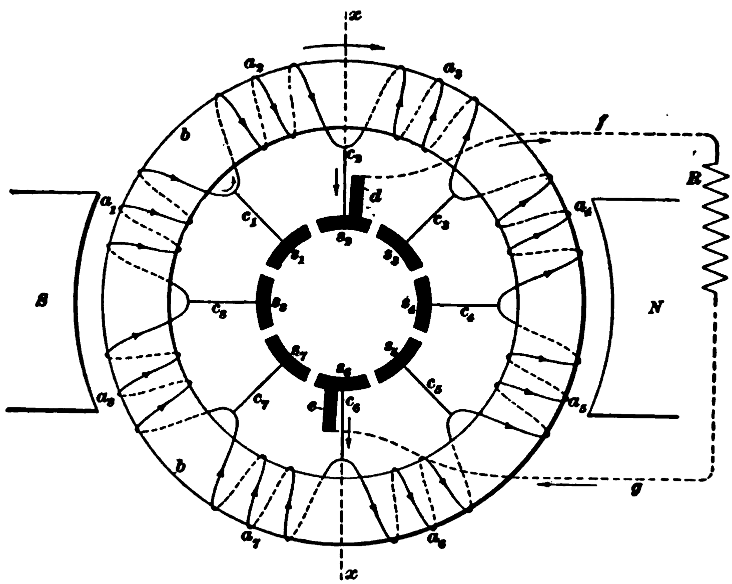


FIG. 42.

also see the connectors c_1, c_2, etc. connecting the junction of the coils with the commutator segments s_1, s_2, etc. N and S are the pole-pieces; N being the north pole, the lines of force will pass from right to left. The armature-core is marked b, and is rotating in the direction indicated by the arrow.

From what has been previously said on the subject, we should easily find that the directions of the induced E. M. F. in the various coils are as indicated by the arrows. We notice now a peculiarity which, at first glance, would seem to make the whole machine inoperative, that the directions of the electromotive forces on one side of the dotted line $x x$ are acting in opposition to those on the other side. But, after some consideration, we find that the two halves of the armature are, in reality joined in parallel, and that whatever currents are flowing in either half, combine at the connector c_2, pass through the latter into the segment s_2, and from there through the positive brush d into the conductor f. After passing through the external resistance R, the current returns through the conductor g, into the negative brush e, then through the segment s_6 and the connector c_6, when it divides, one half of the current flowing through the coil a_6 and the other half through the coil a_7. From either of these coils, the currents continue their upward flow; but it must be remembered that in the next moment the coils a_6 and a_2 will pass the line $x x$, called the **neutral line,** and that then the current will flow through them in opposite directions. In fact, in each coil the direction of the current flowing through it will be reversed twice for each revolution of the armature.

88. It was stated in *Magnetism and Electromagnetism* that the E. M. F. produced in a conductor increased in proportion to the density of the field and the speed of the conductor in a direction at right angles to the lines of force. Neither of these factors is constant in regard to the armature of Fig. 42. The coils a_4, a_5, a_1, and a_8 are passing through a denser field than the coils a_2, a_3, a_6, and a_7; the E. M. F. of the former coils will therefore be higher than that of the latter. An additional detriment is that the last-named coils no longer travel in a direction at right angles to the lines of force, but more or less parallel to them, and that, therefore, when approaching the neutral line, smaller and smaller electromotive forces will be produced in them.

89. Armature Compared With Cells in Parallel Series.—How these electromotive forces of varying heights and directions combine so as to produce one current is shown by means of Fig. 43. We have here 10 cells, arranged in two parallel series of 5 cells. There are, therefore, 5 cells on either side of the neutral line xx, the electromotive forces of the cells at the left running in opposition to those of the cells at the right. The effect is that two currents of electricity will flow, one on either side of the neutral line, and that they will meet at c_1, where they unite into one current of double the amperage; it will then flow through the segment s_1, into the positive brush d, the conductor f, and through the external resistance R. From here it will again return through the conductor g to the negative brush e, pass through the segment s_6, when it will divide again into two separate currents flowing through the cells on either side of the lines x, x to the connector c_1.

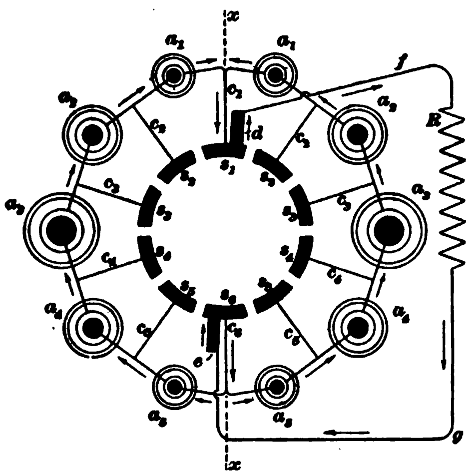


FIG. 43.

If the current, instead of dividing into two branches, had to pass through all of the 10 cells, the loss in voltage would be 10 volts, if we suppose that the internal resistance of a cell is .1 ohm and the current-strength 10 amperes. In the arrangement indicated in Fig. 43, the total resistance of the battery would be (see *Direct Currents*):

$$r' = \frac{s \times r}{p} = \frac{5 \times .1}{2} = .25 \text{ ohm},$$

and the loss in voltage,

$$E = C \times r' = 10 \times .25 = 2.5 \text{ volts},$$

which is one-quarter of the drop with all the cells in series.

It was shown that some of the coils in Fig. 42 developed a higher E. M. F. than others. This has been indicated in Fig. 43 by increasing the size of the cells corresponding in position to those of the coils when having their maximum

E. M. F.; but this must not be understood to mean that an increase of the size of a cell increases its E. M. F. In this instance it must simply be taken as a graphical representation of the relative electromotive forces in the various cells.

90. The diagram in Fig. 43 shows the result of connecting all the coils in series and connecting all the junctions with the commutator-segments. We see that each cell adds its E. M. F. to that of the preceding cells; the same is done by the coils in Fig. 42. It is also evident from Fig. 43 that the connections between the segments and the coils have no influence on the flow of current, and no function to perform, except in that instance when the segments pass under the brush. The segments s_2, s_3, s_4, and s_5, though joined to the connectors c_2, c_3, etc., cannot transmit any current in the positions there indicated, because, for the moment, they are insulated from the rest of the circuit; all the connectors and segments, except those marked c_1, c_6 and s_1, s_6, might therefore be removed without affecting the operation of the dynamo or cells, so far as the position indicated is concerned. Of course, when the armature revolves, all the connectors and segments subsequently come in action.

91. Action of a Dynamo.—We are now able to study an assembled view of a **dynamo** and understand its action in general. In Fig. 44 a dynamo is shown in a diagrammatical view. *A* is the armature, *c* the commutator, *d* and *e* the brushes, and *h* the shaft that supports and drives the armature. The shaft is supported in bearings, not shown in the drawing, at both of its ends. *N* and *S* are the pole-pieces, which receive their magnetism from the electromagnets *E*, E_1, *k*, *l* being the coils, and *i*, *j* the cores of the

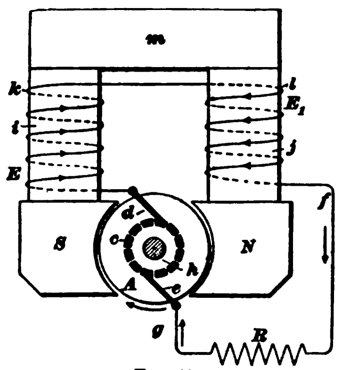


FIG. 44.

electromagnets. The upper ends of the cores are connected by an iron block *m* called a **yoke.**

The current leaves the positive brush *d* and passes directly into the coil *k*, then from this into the other coil *l* and through the conductor *f* into the external circuit *R*. From here, it returns through the conductor *g* and the negative brush *e* to the commutator *c* and the armature *A*. The electromagnets or **field-magnets** as they are usually called, are therefore magnetized by the dynamo itself, and the latter is therefore said to be *self-excited.* If the exciting current of the field-magnets is supplied from some outside source, it is *separately excited.*

CLASSES OF DYNAMOS.

92. Series and Shunt Dynamos.—When the whole current from the armature goes through the field-magnet coils, and they, so to speak, are connected in series, the dynamo is a **series-dynamo,** Fig. 44. If the field-magnet coils and the external circuit are connected in parallel, and therefore only part of the whole current goes through the field-magnet coils, which, in that case, usually are of high resistance, then it is a **shunt dynamo,** Fig. 45. Here the current divides into two parts, the smaller passing directly into the field-magnet coils F, F_1 while the balance goes into the external circuit.

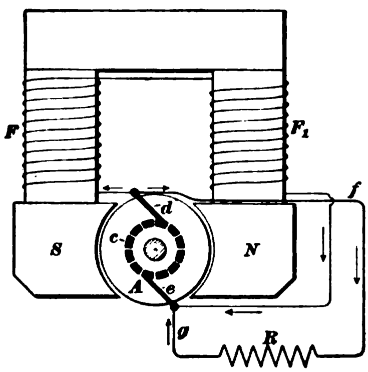


FIG. 45.

93. Compound Dynamo.—When the coils are partly in series and partly in shunt, we have a **compound-wound** dynamo, as shown in Fig. 46.

94. Difference Between Series and Shunt Dynamos. These variations in combining the coils with the armature are for the purpose of regulation, and are determined by the use for which the dynamo is intended. When, as in Fig. 44, the whole current goes through the field-magnet coils, the flow through the latter will be affected by any variation of resistance in the external circuit R. An increase of resistance will diminish the amperage of said coils and also the strength of the magnetic field. In Fig. 45 the conditions are different. Increasing the external resistance causes an increased flow through the coils F, F_1, and therefore strengthens the magnetic field. The E. M. F. of the armature will then increase, and it will be able to send the same current through an increased resistance, if this remains within certain limits. Fig. 46 is a combination of both, and a dynamo of this character is able to regulate itself within wide limits.

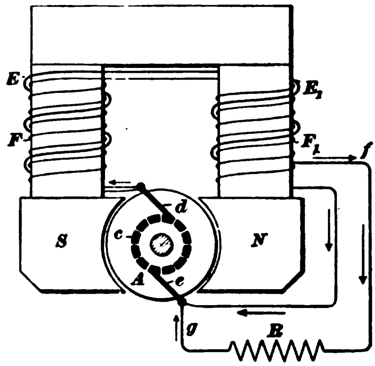


FIG. 46.

95. Alternators.—The dynamos so far considered deliver a continuous current, because the commutator rectifies the various currents in such a manner that they run in the same direction. The dynamo, then, in reality provides an alternating current. If we therefore excite the field-magnet coils from some exterior source, remove the commutator, and replace it by two simple contact-rings with brushes, we would, if the armature is properly wound, receive an alternating current from the brushes. The machine would then no longer be a direct-current, but an alternating-current dynamo, or what is called an **alternator.**

MOTORS.

96. General Principles.—The effects produced in a conductor moving in a magnetic field were described in *Magnetism and Electromagnetism*. If the conditions there represented be reversed and a current sent through the conductor while it is situated in a magnetic field, what would be the result? The conductor would move, but in a direction opposite to that which would produce an E. M. F. acting in the same direction as that of the current now flowing. For instance, if, in Fig. 47, the conductor were moving across the field in the direction indicated by the arrow, an E. M. F. would be created that would tend to send a current down through the paper. If, on the other hand, it is intended to move the conductor in the same direction by means of a current, sent through it from some external source, the current must be sent through it in an upward direction. The illustration will show the reasons for this. It is observed that the lines of force, encircling the conductor, and which are produced by the upward passing current, on one side travel in the same direction as the lines of force belonging to the pole-pieces *N*, *S*; a repulsion will therefore take place, as explained in *Magnetism and Electromagnetism*. On the other side, the lines of force travel in opposite directions and an attraction will be effected. Both of these forces tend to move the conductor in the direction indicated by the arrow. This reaction between an active conductor and a magnetic field is the principle on which an **electric motor** is based.

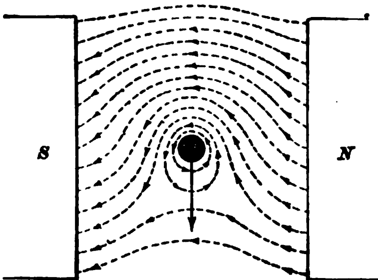


FIG. 47.

It is therefore possible to change a dynamo into an electric motor by supplying it with a current through the brushes; and, conversely, it is also possible to change an electric motor into a dynamo by supplying it with mechanical energy through the shaft.

97. Counter-Electromotive Force.—As soon as a motor-armature begins to rotate, it tends to act as if belonging to a dynamo, and begins to create an E. M. F. in opposition to that which sends a current through the brushes. This E. M. F. is called a *counter* E. M. F., and it is clear that the E. M. F. applied to the terminals must at least be equal to the counter E. M. F. plus the fall of potential in the armature.

98. Uses of Dynamos and Motors.—Dynamos are not used as frequently in electrotherapeutics as voltaic batteries, the latter being more convenient when only small units of electric energy are required. Sometimes, when larger volumes of current are needed, and electric circuits used for city lighting are at hand, these circuits may be utilized for operating an electric motor, while the latter again may furnish the necessary power for running a small dynamo. The high voltage of the lighting mains, which usually is either 110 or 220 volts pressure, may in this manner be changed into a voltage sufficiently low to be used in connection with an electric cautery.

99. As there are dynamos that produce continuous, and others that produce alternating, electromotive forces, so there are motors capable of using either of these electromotive forces, though, as a rule, a motor built for one of these varieties of E. M. F. is unable to be run by the other. It is also to be noticed that a motor is designed for a special speed and E. M. F., and, when these conditions are fulfilled, it is showing its highest efficiency. If compelled to run at other speeds or with higher or lower electromotive forces than those for which it was intended, it is likely to run at a certain disadvantage and be unable to utilize as much of the power supplied as it otherwise would. A motor may also be operated by means of a storage or a primary battery, and in any of these cases its speed is regulated by means of a suitable rheostat.

UNITS.

FUNDAMENTAL UNITS.

100. The **units** used in electricity and magnetism have partly been explained at different times, but it is advisable to repeat the definitions already given and to add others, for the sake of easy reference, and in order to show more clearly the relation and derivation of the various units.

The units are divided into the following subdivisions: fundamental units, derived units, electrostatic units, magnetic units, electromagnetic units, and practical units.

The absolute and practical units are based upon the three **fundamental units** of *length*, *time*, and *mass*, which are defined as follows:

101. Unit of Length.—The **centimeter,** or the **unit of length,** represents $\frac{1}{1000000000}$ of the distance from the pole to the equator on the surface of the earth, and is equal to .3937 inch, or 1 inch equals 2.54 centimeters, nearly. A **square centimeter** is the area contained in a square, each of whose sides is 1 centimeter in length; 1 square centimeter equals .155 square inch, or 1 square inch equals 6.45 square centimeters, nearly. A **cubic centimeter** is the volume contained in a cube, each of whose edges is 1 centimeter in length; 1 cubic centimeter equals .06102 cubic inch, or 1 cubic inch equals 16.387 cubic centimeters.

102. Unit of Mass.—The **gram,** or the **unit of mass,** or *quantity*, of *matter*, represents the quantity of matter contained in a cubic centimeter of pure water at the temperature of its maximum density, which is 4° C., or 39.2° F., and is equal in weight to 15.432 grains.

103. Unit of Time.—The **second,** or the **unit of time,** represents $\frac{1}{86400}$ of a mean solar day.

104. Absolute, or C. G. S., Units.—The system of units derived from these are named the **absolute,** or **C. G. S., system,** to distinguish it from other systems based on other fundamental units.

105. Derived Units. — From these fundamental units the following secondary units are derived:

The **unit of velocity,** or the rate at which a body changes its relative position, is determined by dividing the distance in centimeters through which a body travels by the time in seconds required to travel that distance. The unit of velocity is, therefore, 1 centimeter per second.

The **dyne,** or the **unit of force,** is that force which, by acting upon a mass of 1 gram for 1 second, can give to it a velocity of 1 centimeter per second.

The **erg,** or the **unit of work,** is the amount of work performed when a force of 1 dyne is overcome through a distance of 1 centimeter. It has already been stated that the practical unit of work in electrical measurements was the **joule;** 1 joule is equal to 10,000,000 ergs.

The **unit of power,** or the rate of expending energy, is 1 erg per second. Consequently, as the watt is equal to 1 joule per second, it must also equal 10,000,000 ergs per second.

106. Electrostatic Units.—The following units have no special names:

The **unit quantity** is a quantity of electricity that is able to repel another similar and equal quantity with a force of 1 dyne at a distance in air of 1 centimeter.

The **unit potential** is that potential which requires the expenditure of 1 erg of work to bring a unit quantity of electricity from zero potential to that potential.

The **unit electromotive force,** or **difference of potential,** exists between two points if a unit quantity of electricity will do 1 erg of work in passing from one point to the other.

The **unit current** is one that conveys a unit quantity of electricity through a conductor in 1 second.

The **unit of capacity** is possessed by a conductor if a charge of 1 unit of electricity brings it up to unit potential.

The **unit resistance** of a conductor is that which requires unit electromotive force to send a unit current through it.

107. Magnetic Units.—The **unit magnetic pole** is one of such strength that it, at a distance of 1 centimeter in air, repels a similar pole with a force of 1 dyne.

The **magnetic potential** at a point, due to a magnet, is the work required to remove a unit magnetic pole from that point, against the magnetic attraction, to an infinite distance. This work is measured in ergs.

The **unit difference of magnetic potential** exists between two points when it requires the expenditure of 1 erg of work to bring a (north or south) unit magnetic pole from one point to the other against the magnetic forces.

The **strength of a magnetic field** is measured by the force it exerts upon a unit magnetic pole; therefore, the **unit intensity** of a magnetic field is that which acts on a unit pole with a force of 1 dyne.

108. Electromagnetic Units.—The **unit strength of current** is one which in a wire of 1 centimeter length, bent so as to form an arc of a circle of 1 centimeter radius, exerts a force of 1 dyne on a unit magnetic pole placed at the center.

The **unit quantity of electricity** is the quantity that a unit current conveys in 1 second.

The **unit electromotive force, or difference of potential,** is that which must be maintained between two points on a conductor, in order that unit current may do 1 erg of work in 1 second.

The **unit resistance** of a conductor is that which permits a unit current to flow through it, when unit electromotive force is maintained between its ends.

The **unit capacity** of a condenser is that which a unit quantity of electricity will raise to unit potential.

PRACTICAL UNITS.

109. Index Figures.—Some of the absolute, or C. G. S., units would be either too large or too small for practical use. The following units, called **practical electric units,** have therefore been selected so as to be of a magnitude convenient for ordinary use. They are decimal multiples of the absolute units; but, as it would require numerous figures to express the value of the practical units in absolute units, a system of writing has been adopted in which, by means of index figures, these large figures can be reduced to a number of few figures.

The index may either be *positive* or *negative*, and signifies in the first case the number of tens by which the figure is to be *multiplied*, and in the latter case the number of tens by which it is to be *divided*. For instance, $3 \times 10^2 = 3 \times 10 \times 10 = 3 \times 100 = 300$; $2 \times 10^3 = 2 \times 10 \times 10 \times 10 = 2{,}000$; $4 \times 10^6 = 4{,}000{,}000$. $3 \times 10^{-2} = \frac{3}{10 \times 10} = \frac{3}{100} = .03$; $4 \times 10^{-3} = \frac{4}{10 \times 10 \times 10} = \frac{4}{1{,}000} = .004$; $2 \times 10^{-6} = \frac{2}{10^6} = \frac{2}{1{,}000{,}000} = .000002$; $\frac{1}{5} \times 10^3$ would be $\frac{1}{5} \times 1{,}000 = 200$, while $\frac{1}{5} \times 10^{-3}$ would equal $\frac{1}{5} \times \frac{1}{1000} = \frac{1}{5000} = .005$.

110. Unit of Current.—The **absolute electromagnetic unit of current** is too large for ordinary purposes, and the practical unit of current has therefore been reduced to one-tenth part of the former unit, and is then called *1 ampere.* An ampere is thus 10^{-1} of an absolute (electromagnetic) unit of current-strength.

A current of electricity, when passing through water, decomposes it into its two elements, hydrogen and oxygen. The quantity of water decomposed is proportional to the strength of the current flowing, and also to the time during which it flows. Consequently, a unit strength of current can be conveniently adopted by agreeing that it is that strength of current which will decompose a certain quantity of water in a certain time, and agreeing upon the quantity of water and the time.

By universal agreement, 1 ampere is that strength of current which will decompose .00009324 *gram,* or .0014388 *grain,* of water in 1 second. It will also, in 1 hour, deposit 4.024 grams, or 60.52 grains, of silver in a silver cell, which is at the rate of .001118 gram, or .01681 grain, of silver per second. This is almost exactly 1 grain of silver per minute.

111. Unit of Electromotive Force.—The **absolute electromagnetic unit of electromotive force** is so small that it would take 100,000,000 of these units to express the E. M. F. of a single Daniell's cell. When it comes to high E. M. F., the number would be enormous, and it has therefore been decided to take 100,000,000 (10^8) absolute units, and of these make a new unit, called *1 volt.*

It was stated in *Magnetism and Electromagnetism* that if a conductor, in passing through a magnetic field, cuts lines of force at the rate of 1 line of force per second, 1 absolute unit of potential was generated. It follows, therefore, that to generate 1 volt the conductor must cut across 100,000,000 (10^8) magnetic lines of force per second. The E. M. F. of a Daniell's cell is about 1.1 volts.

112. Unit of Resistance.—The **practical unit of resistance** is 1,000,000,000 times as great as the absolute electromagnetic unit. The units of the volt and ampere determine the magnitude of this unit, as, according to Ohm's law,

$$1 \text{ unit of resistance} = \frac{1 \text{ unit of electromotive force}}{1 \text{ unit of current}};$$

but, as the practical unit of E. M. F. is 100,000,000 absolute units, and the practical unit of current is $\frac{1}{10}$ of the absolute unit, it follows that 1 practical unit of resistance $= \frac{100,000,000}{\frac{1}{10}}$ $= 1,000,000,000$ (10^9) absolute electromagnetic units of resistance.

113. This practical unit of resistance has been named *1 ohm.* The true ohm is the resistance offered by a column of mercury 106.3 centimeters high and 1 square millimeter in sectional area at the freezing-point of water, or 0° C.

The legal ohm is the unit of resistance generally employed in technical measurements, although it is probably .3 per cent. smaller than the true ohm. One legal ohm is the resistance offered by a column of mercury 106 centimeters high and 1 square millimeter of sectional area at freezing-point of water, 0° C. The dimensions of the column, expressed in inches, are 41.7323 inches high and .00155 square inch of sectional area.

The resistance of 100 yards of ordinary iron telegraph-wire is about 1 ohm.

114. Unit of Quantity.—The **practical unit of quantity** is the **coulomb**; it is $\frac{1}{10}$ (10^{-1}) of the absolute unit of quantity of the electromagnetic system. It can deposit .001118 gram of silver.

115. Unit of Capacity.—The **farad** is the **practical unit of capacity** and is $\frac{1}{1000000000}$ (10^{-9}) of the absolute electromagnetic unit of capacity.

116. Unit of Power.—The **watt, or volt-ampere**, is the **practical unit of power.** It is obtained by multiplying together volts and amperes. One watt equals 1 joule per second, therefore .7373 foot-pound per second, or $\frac{.7373}{550} = \frac{1}{746}$ horsepower. 1,000 watts equals 1 kilowatt.

117. One *watt-second* is 1 watt expended for 1 second. One *watt-hour* is the energy expended by 1 watt for 1 hour, or 2,654.4 foot-pounds.

One *kilowatt-hour* is the quantity of energy supplied in 1 hour by a current of such voltage that the product of volts, amperes, and hours comes to 1,000; for instance, a current of 5 amperes at 20 volts for 10 hours, or a current of 100 amperes at 10 volts for 1 hour.

118. Even these units are sometimes either too large or too small, and prefixes of *mega*, *micro*, and *milli* are then used. They facilitate the calculations and measurements of exceedingly large or small quantities.

Mega means "one million"; *micro*, "one-millionth part"; and *milli* "one-thousandth part."

For instance, 1 *microhm* is equal to $\frac{1}{1000000}$ ohm. Therefore, to express the resistance in microhms, multiply the resistance in ohms by 1,000,000; and, conversely, to express the resistance in ohms, divide the resistance in microhms by 1,000,000.

The *megohm* is a unit of resistance that is equal to 1,000,000 ohms, and is used chiefly to measure the resistance of bad conductors and insulators.

The *microfarad* is $\frac{1}{1000000}$ farad; a *milliampere* is the thousandth part of 1 ampere.

119. Ratio of the Electrostatic to the Electromagnetic Units.—The dimensions adopted for similar units in these two systems are not the same. It would go beyond the limits of this Section to explain why this is so, and it must therefore suffice to simply call attention to the fact and point out how great the differences are.

The following table shows the ratio between the practical, the electrostatic (C. G. S.), and the electromagnetic (C. G. S.) units:

Characteristic	Practical Units	Electromagnetic (C. G. S.) Units	Electrostatic (C. G. S.) Units
Current-strength . . .	1 ampere	10^{-1}	3×10^{9}
Quantity	1 coulomb	10^{-1}	3×10^{9}
Potential	1 volt	10^{8}	$\frac{1}{3} \times 10^{-2}$
Resistance	1 ohm	10^{9}	$\frac{1}{9} \times 10^{-11}$
Capacity	1 farad	10^{-9}	9×10^{11}

The ratio between the electromagnetic and the electrostatic units is therefore as follows:

Electromagnetic (C. G. S.) Units		Electrostatic (C. G. S.) Units
1 unit of current-strength	=	3×10^{10} units.
1 unit of quantity	=	3×10^{10} units.
1 unit of potential	=	$\frac{1}{3} \times 10^{-10}$ units.
1 unit of resistance	=	$\frac{1}{9} \times 10^{-20}$ units.
1 unit of capacity	=	9×10^{20} units.

We see from the first table that the practical unit, *ampere*, is $\frac{1}{10}$ of the electromagnetic (C. G. S.) unit of current-strength, and that the practical unit, *volt*, is equal to 100,000,000 electromagnetic (C. G. S.) units of potential. The practical unit, *ohm*, equals 1,000,000,000 electromagnetic (C. G. S.) units of resistance.

From the last table it is seen that the electromagnetic unit of quantity is 30,000,000,000 times greater than the corresponding electrostatic unit, while on the other hand the electrostatic unit of potential is 30,000,000,000 times greater than the electromagnetic unit of potential.

A SERIES OF QUESTIONS

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the questions contained in the following pages are divided into sections corresponding to the sections of the text of the preceding pages, so that each section has a headline that is the same as the headline of the section to which the questions refer. No attempt should be made to answer any of the questions until the corresponding part of the text has been carefully studied.

DIRECT CURRENTS.

EXAMINATION QUESTIONS.

(1) Why is the expression "producing" electricity incorrect?

(2) What do you understand by electricity?

(3) Define electrification.

(4) What is the function of the ether?

(5) Is ether present in a vacuum? How is this proved?

(6) How did the word current come to be applied to electricity and magnetism?

(7) What do you understand by electrical resistance?

(8) What causes the electric current to flow from one point in the electric circuit to another point in the same circuit?

(9) (*a*) Define electromotive force. (*b*) What are the other terms often used instead of electromotive force?

(10) What is a volt?

(11) Define (*a*) the coulomb; (*b*) the ampere.

(12) Explain the difference between current-tension and current-intensity.

(13) Explain briefly why a loss of pressure occurs when a current is flowing through a conductor.

(14) What is (*a*) the ohm? (*b*) the microhm?

(15) On what does the resistance of a conductor depend?

(16) If a copper conductor 100 feet in length and .2 square inch in cross-sectional area has a resistance of 5,000 microhms, what will be the resistance in ohms of the same conductor when its length is 1 mile?

(17) What will be the resistance in ohms of 100 feet of a copper conductor, the area of whose cross-section is .1 square inch, when the resistance of 1 cubic inch of the same material is .6433 microhm?

(18) State Ohm's law.

(19) A difference of potential of 110 volts exists between the terminals of a conductor whose resistance is 20 ohms; find the current flowing through the circuit.

(20) A current of 10 amperes is flowing through a circuit whose resistance is 12 ohms; what voltage is required?

(21) A circuit has an available pressure of 220 volts; what is its resistance if a current of 40 amperes can flow through it?

(22) (*a*) What is the mechanical unit of work? (*b*) What is the electrical unit of work? (*c*) What is the relation between them?

(23) Define the joule.

(24) State the relation (*a*) between the joule and the watt; (*b*) between the coulomb and the ampere.

(25) Find the amount of work performed, in foot-pounds, when a current of 25 amperes flows for 2 hours, under a pressure of 100 volts.

(26) Find the horsepower developed in the example of question (25).

(27) Enumerate the sources of E. M. F.

(28) What occurs when two dissimilar metals, as zinc and copper, are immersed in a vessel containing acidulated water?

(29) What takes place when the exposed ends of the elements are connected by a wire of conducting material?

(30) Define (*a*) voltaic cell; (*b*) voltaic couple; (*c*) voltaic element.

(31) What effect does an increase in temperature have on a metallic conductor as regards its resistance?

(32) What do you understand (*a*) by the generating-plate? (*b*) by the collecting-plate?

(33) In any voltaic combination, which is the generating-plate?

(34) Define (*a*) anode; (*b*) cathode.

(35) What chemical actions take place in the voltaic cell in which the electrolyte is dilute sulfuric acid, the generating- and collecting-plates zinc and copper?

(36) What is meant by local action?

(37) What are the impurities in commercial zinc?

(38) How is local action prevented?

(39) Explain what is meant by polarization and depolarization as applied to the voltaic cell.

(40) Name the various methods employed for preventing polarization in the cell.

(41) Why does the accumulation of hydrogen on the collecting-plate transform the collecting-plate into a generating-plate?

(42) (*a*) For what purposes are primary batteries chiefly used? (*b*) What limits their use on a large scale?

(43) If the external resistance of a circuit is low relative to that of a number of cells in series, how can the current-strength be increased?

(44) A battery of 6 cells is available to send a current through a circuit of high resistance. How should they be arranged to give a current of maximum strength?

(45) (*a*) Give a full description of the Leclanché cell. (*b*) State fully the function of the manganic dioxid used in this cell.

(46) What cell is used in medical practice more than all others taken collectively, and why?

(47) Describe the general construction of a dry cell.

(48) What kind of cells should be used for cautery work? Give reasons.

(49) State the advantages of the process invented by Faure over that of Planté in the preparation of accumulator-plates.

(50) What effect occurs if accumulators are discharged below 1.9 volts?

(51) How does this effect influence the utility of the accumulator?

(52) What determines the voltage and amperage of the current of an accumulator?

(53) What effect does the rate of discharge have (*a*) on the output of an accumulator? (*b*) on the life of the plates?

(54) How are accumulators charged?

(55) State the percentage of the charging-current that a storage-battery yields.

(56) What precaution is necessary in connecting the poles of an accumulator?

(57) What are the advantages of the chlorid accumulator-plates over the paste types of plates?

(58) Explain the advantages of accumulators for medical purposes where large currents are required.

(59) How would you modify Ohm's law, $C = \frac{E}{R}$, if you were going to apply it to a circuit containing a counter E. M. F., in addition to the ohmic resistance?

(60) What is the specific gravity of the electrolyte of an accumulator in working order?

(61) In selecting batteries for medical purposes, what should be the objects in view?

(62) What are the advantages of making one battery serve as many purposes as possible?

(63) Why should binding-posts, connections, etc. be kept thoroughly clean and polished?

(64) When a battery has been used, why should the electrodes be placed away in a careful manner?

(65) How can you determine which is the positive and which is the negative pole of the battery?

(66) What is a grounded circuit?

(67) Define (*a*) external circuit; (*b*) internal circuit.

(68) How do you connect cells in parallel?

(69) How do you connect cells in series?

(70) What do you understand by a parallel-series connection?

(71) Can an electric current flow through a circuit without a loss of pressure?

(72) Does the current-strength change in any part of the circuit?

(73) Does the voltage change? Give reasons.

(74) What determines the current-strength of any battery?

(75) What does the fall of potential really represent?

(76) What do you understand by the term shunt?

(77) State the law of the divided circuit.

(78) Three conductors *a*, *b*, and *c* have resistances of 3, 4, and 6 ohms, respectively. If they are connected in parallel, what will be their joint resistance?

(79) If the individual resistances of two conductors are equal, what is their joint resistance when connected in parallel?

(80) When the individual resistances of two conductors in parallel are unequal, how do you determine their joint resistance?

(81) How do you find the joint resistance of three or more conductors in parallel?

(82) How do you find the individual current in any branch of a derived circuit?

(83) How do you find the drop of potential in the external and internal circuit?

(84) Define (*a*) direct E. M. F.; (*b*) alternating E. M. F.; (*c*) pulsating E. M. F.; (*d*) continuous E. M. F.; (*e*) intermittent E. M. F.

(85) How many alternations are there in a cycle?

(86) Define, by an illustration, what you understand by frequency.

(87) When is an E. M. F. positive, and when negative?

(88) When does an E. M. F. become alternating?

(89) How many alternations are there in 100 cycles?

MAGNETISM AND ELECTROMAGNETISM.

EXAMINATION QUESTIONS.

(1) Define magnetism and electromagnetism.

(2) What effects are produced on a conductor through which an electric current is flowing?

(3) In how many ways may magnetism be produced?

(4) How are the ends of a magnetic needle designated?

(5) Show, by means of an illustration, how a freely suspended magnetic needle will behave when brought near a magnet.

(6) What simple method is there for showing the direction of the magnetic lines about a magnet?

(7) Define (*a*) lines of magnetic force; (*b*) magnetic field; (*c*) magnetic flux.

(8) On what two quantities does the strength of every magnetic circuit depend?

(9) (*a*) What is the unit of magnetomotive force? (*b*) What is the unit of reluctance? (*c*) What is the unit of magnetic flux? (*d*) Give an equation showing the relation between these units, and state to what other equation between electrical units it is analogous.

(10) What do you understand by reluctance?

(11) What do the lines of magnetic force show?

(12) What is the medium through which magnetic forces are supposed to act?

(13) By which pole are th lines of magnetic force supposed to enter a magnet, and from which pole do they leave?

(14) (*a*) What will take place between lines of force entering two south poles that face each other? (*b*) What

will take place between lines of force emanating from two north poles facing each other?

(15) State the law on which this phenomenon depends.

(16) What important difference is there between a charge of electricity on a conductor and the magnetism of a magnet?

(17) When a piece of steel or iron is magnetized, what rearrangement takes place in the relative positions of the molecules?

(18) What is meant by induced magnetism?

(19) Show how you would magnetize a bar of steel or iron by means of a permanent magnet.

(20) Suppose a long bar magnet is broken into several short pieces. Show how it is that each short piece will be an independent magnet by itself, having a north and a south pole.

(21) What is meant by the length of a magnetic circuit?

(22) If two opposing magnetic fields are brought together, how will the lines of force arrange themselves?

(23) In what way does reluctance differ from resistance?

(24) How do the dimensions of a magnetic circuit affect the reluctance?

(25) How may magnetic circuits be classified?

(26) What is meant by magnetic density?

(27) A bar of iron 3 inches wide and 5 inches broad has 600,000 lines of force flowing through it in the direction of its length. What is its magnetic density per square inch?

(28) (*a*) How can the existence of a magnetic field around a conductor conveying an electric current be proved? (*b*) How will starting and stopping the current affect the magnetic field around the conductor?

(29) Give a rule for determining the relative directions of an electric current in a conductor, and the lines of force around it.

(30) What will be the action between the fields of two parallel conductors, the currents of the conductors flowing in opposite directions?

(31) Describe a solenoid.

(32) Give the rule for determining the relative directions of the current and the lines of force in a solenoid.

(33) Define permeability.

(34) On what does the magnetic flux through a solenoid depend?

(35) Why is the magnetic flux increased when an iron or steel core is inserted in a solenoid?

(36) Why must the wire of a solenoid be insulated?

(37) Make a sketch of a simple form of an electromagnet.

(38) Why is a horseshoe magnet more efficient than a straight bar magnet of the same length?

(39) If a magnet is introduced into or withdrawn from a solenoid with a galvanometer in circuit, what will take place?

(40) (*a*) Give Fleming's rule for determining the direction of the induced E. M. F. in a conductor cutting across a magnetic field. (*b*) State Ampere's rule for determining the same.

(41) Under what conditions will a current flow through a conductor that is moving in a magnetic field?

(42) On what does the magnitude of the E. M. F. in a conductor cutting lines of force depend?

(43) Enumerate the various means of inducing an E. M. F.

(44) Explain the phenomenon of induction.

(45) Discuss the behavior of the magnetic field of a solenoid as the circuit is opened and closed.

(46) What are eddy, or Foucault, currents, and how are they produced?

(47) What effect have they on metal in which they circulate?

(48) How may Foucault currents be prevented?

(49) Explain, in your own words, the operation of the primary coil shown in Fig. 56.

(50) Explain the manner in which the formation of a spark is prevented by means of a condenser when the current of a primary coil is broken.

(51) What is the shield, and for what purpose is it used in the induction-coil?

(52) In the Dubois-Reymond type of induction-coil, how is the E. M. F. at the electrodes varied?

(53) Why is it that, when switch W, Fig. 67, is in contact with S_1, no current from coil S_2 is sent through the external circuit?

(54) Why is it not possible to increase the E. M. F. of an induction-coil indefinitely by increasing the frequency of the "make" and "break" of the circuit?

(55) How is the current affected as the frequency of vibration is increased?

(56) How may the Geissler tube be used to determine whether the E. M. F. of the coil is sufficiently high to produce the physiological effects of high-tension currents?

(57) How may the vibrator be tested for irregularities in its movements?

(58) What is the difference between the effective E. M. F. and the maximum E. M. F. of an alternating current?

(59) How may the effective current-strength of an alternating current be measured?

(60) What do you understand by the so-called extra current of the primary circuit?

(61) Explain why this extra current is so much stronger than the make-current.

(62) If the conductor C, Fig. 42 (a), is moving upwards what will be the polarity of the end n?

(63) If the conductor *C*, Fig. 45, revolved in the opposite direction, what position would the point C_1 occupy in the curve Fig. 45 (*b*)?

(64) What purpose does the core *I*, Fig. 47, serve?

(65) By what means may alternating currents be produced for therapeutic purposes?

ELECTROSTATICS AND HIGH-FREQUENCY CURRENTS.

EXAMINATION QUESTIONS.

(1) Define static electricity.

(2) Explain the meaning of "positively electrified" and "negatively electrified" as applied to a body having a static charge.

(3) How is the interaction of two electrically-charged bodies analogous to the interaction of two magnets?

(4) When is a body said to be charged?

(5) Explain the difference between conductors and insulators.

(6) State two of the most important laws of electricity.

(7) What do you understand by the electric series?

(8) In how many ways do charges on bodies differ?

(9) How may the presence of an electric charge on a body be detected?

(10) Describe (*a*) the gold-leaf electroscope; (*b*) the quadrant-electroscope; and (*c*) the torsion-balance.

(11) Define electrostatic unit of quantity of electricity.

(12) What is meant by an induced charge?

(13) Explain the meaning of the terms "free charge" and "bound charge."

(14) How is the induced charge on a body affected by the distance of that body from the inducing body?

(15) State the law of inverse squares.

(16) What do you consider the most important phenomenon of static electricity?

(17) Define electrostatic field.

(18) How can you explain why a neutral pith-ball is attracted by a rubbed glass rod?

(19) What will happen if two unequal charges unite, provided the charged bodies are of equal size and of the same shape?

(20) Define inductive capacity.

(21) What distinguishes dielectrics from insulators?

(22) Is it unimportant what substance resides between two charged bodies?

(23) What substance offers the most resistance to induction?

(24) May a good insulator be a poor dielectric?

(25) Are all dielectrics insulators?

(26) What conditions govern the potential of a charge?

(27) Describe the electrophorus, and explain how it can be made to charge a Leyden jar.

(28) Upon what part of the body does the static charge reside?

(29) State the exception to the law that static charges reside only on the external surfaces of bodies.

(30) Does electricity in motion flow both along the surface and through the body of a conductor?

(31) What do experiments show in regard to the amount of electricity on the edges, corners, and flatter parts of bodies?

(32) (*a*) Where is the maximum density of two similarly-charged spheres placed in contact with each other? (*b*) Where is the minimum density?

(33) What are necessary when it is desired to secure a rapid discharge of electrical charges?

(34) What is the unit of electrostatic capacity?

(35) What is a microfarad?

(36) The potential of a conductor is 30 volts when it has a charge of 150 coulombs. What is its capacity in microfarads?

(37) On what does the number of coulombs residing on a charged sphere depend?

(38) What is necessary to know before an idea can be had of the quantity of electricity on a given conductor?

(39) What is a farad equal to?

(40) Explain the construction of a condenser.

(41) Is the capacity of a conductor increased or decreased by being placed near a conductor electrified with the opposite kind of charge?

(42) Upon what does the capacity of a condenser depend?

(43) Describe the Leyden jar and explain its action.

(44) Where is the charge of the Leyden jar located?

(45) Why does the dielectric of the Leyden jar sometimes break?

(46) What is meant by "residual charge"?

(47) Describe the construction of a battery of Leyden jars.

(48) What is the objection to the electrophorus as an induction-apparatus?

(49) Into what two classes may static machines be divided?

(50) Which type of static machine is now most generally used by physicians?

(51) What purpose does the Wimshurst machine serve in a Holtz machine?

(52) Describe clearly the Holtz machine and its mode of action.

(53) What voltage is required to produce an electric breeze?

(54) What is the potential difference required to send a spark between two metal balls separated by an air-gap of 1 inch?

(55) How do you estimate the maximum potential of a static machine?

(56) When you connect the prime conductors of a static machine with a piece of copper wire, what is the effect?

(57) What is the nature of a spark produced by a static discharge?

(58) What three methods are there by which a discharge can occur?

(59) What is the nature of the discharge from the Leyden jar?

(60) Explain the manner of producing static induced currents.

(61) What is the difference between the discharge of the static machine, the discharge of the Leyden jar, and the discharge of a lightning stroke?

(62) What is the action of the small brushes on the wire arms of the Wimshurst machine?

(63) To what extent does self-induction in the circuit affect static discharges?

(64) Describe the means of inductively changing the potential of an insulated body from positive to negative.

(65) What is meant by high-frequency currents?

(66) What is a condenser electrode?

ACCESSORY APPARATUS.

EXAMINATION QUESTIONS.

(1) (*a*) What are cell-selectors? (*b*) Why are they used?

(2) Explain the difference between single-handed and double-handed selectors, and state where each kind is used.

(3) Explain how the selectors can be used as current-regulators.

(4) What is a switchboard?

(5) How do cell-selectors compare with rheostats as current-regulators?

(6) What precaution should be observed in using cell-selectors?

(7) What is the function (*a*) of the ammeter? (*b*) of the voltmeter?

(8) On what principle is the operation of the modern ammeter and voltmeter based?

(9) What is meant by a dead-beat instrument?

(10) How are Weston voltmeters and ammeters made dead-beat?

(11) Suppose you were going to place a Weston ammeter in a circuit through which a current of unknown strength is flowing. Would you connect your ammeter so as to give readings on the high scale (0 to 500 milliamperes) or on the low scale (0 to 10 milliamperes)? Give your reasons.

(12) How do the coils of ammeters differ from those of voltmeters with respect to their resistance?

(13) What effect on the circuit does short-circuiting a voltmeter have?

(14) Suppose a current is flowing through a circuit containing an ammeter and a voltmeter. (*a*) What would be the effect of disconnecting the ammeter? (*b*) What would be the effect of disconnecting the voltmeter?

(15) What substances are generally used for rheostats?

(16) If a rheostat increases the resistance of a circuit, what effect does this have on the available E. M. F. of the battery?

(17) Make a rough sketch of Fig. 28, and indicate by arrows the direction of the current in the voltmeter-circuit.

(18) Explain how increasing the distance between *e* and *d*, Fig. 13, increases the resistance of the circuit.

(19) What E. M. F. does the voltmeter in Fig. 24 indicate?

(20) Does the ammeter, Fig. 24, measure the current flowing through the battery?

(21) What E. M. F. does the voltmeter in Fig. 26 indicate?

(22) Does the ammeter in Fig. 26 indicate the total current flowing through the battery?

(23) In Fig. 41, *e* and *f* move in the same magnetic field. How can you account for the fact that the induced E. M. F. along *e* is in the opposite direction to that of *f*?

(24) Describe the commutator, and state its function.

(25) What is the function of the brushes on a dynamo-electric machine?

(26) What is the armature and what the core of the dynamo-electric machine?

(27) Why is the core of a dynamo-electric machine nearly always made of laminated iron?

(28) Explain the difference between a ring armature and a drum armature?

(29) What is the difference between a self-excited and a separately-excited dynamo?

(30) What is (*a*) a shunt dynamo? (*b*) a series dynamo? (*c*) a compound dynamo? (*d*) Illustrate these dynamos by rough sketches.

(31) What difference is there in mechanical construction between a dynamo and a motor?

(32) (*a*) Describe the difference between connecting a patient in series and in shunt with a rheostat, as regards the path of the current. (*b*) What is the difference in regulation between the two?

(33) What is meant by a volt-selector, and where is it generally used?

(34) For what purpose is a current-selector utilized?

(35) What is an indifferent electrode?

(36) Why are covered electrodes used?

(37) What function does the water in a hydro-electric bath perform?

(38) What E. M. F. is induced in a conductor when it crosses the line $x x$, Fig. 42?

(39) What is meant by current-density?

(40) If the current through a certain body is 600 milli-amperes, and the cross-sectional area is 4 square feet, what is the current-density per square foot?

(41) If the current-strengths of two conductors are the same, and both are of the same specific resistance, how can the current-density be much greater in one of them?

(42) If a person is placed in an ordinary bipolar bath, and a current sent through the latter, is the current-density through all parts the same?

(43) What is the main difference between a monopolar and a bipolar bath?

(44) Is the total current passing through a bath an indication of the current received by a body submerged in the water?

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